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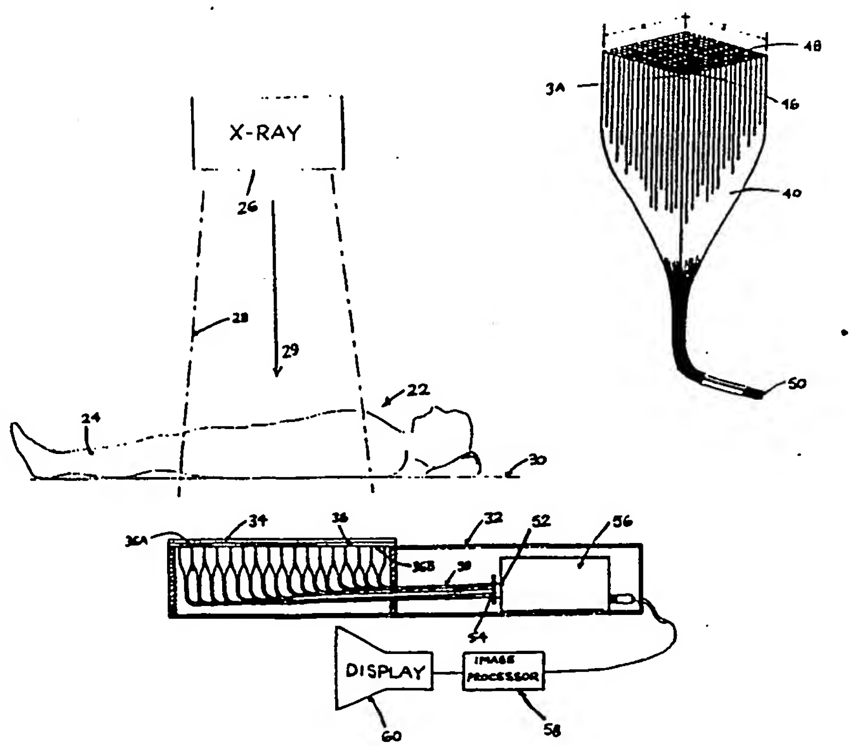
(54) Title: FIBER OPTIC BEAM-IMAGING APPARATUS WITH PLASTIC REDUCER BUNDLES AND METHOD

(57) Abstract

Apparatus for generating a reduced-scale optical image of an x-ray beam pattern or the like includes an optical fiber assembly (38) which forms a two-dimensional input array (42) and whose output ends form a reduced-scale two-dimensional output array (44). A beam converter (34) converts the irradiation beam (29) to a corresponding electron beam, and this beam is converted to a two-dimensional light image of the beam which is directed onto the input array (42). In one embodiment, the optical fibers form an array (38) of multifiber reducers (40) which are tapered on progressing between input (48) and output ends (50). In other embodiments, the input array (78, 113) is formed by the elongate input fiber regions of fibers (77, 114) having a parallel, side-by-side arrangement, and the two dimensional image is produced by scanning a linear electron beam and light-generating strip (76) transversely along the length of the array, or by rotating the array (113) below a full-area electron beam.



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FIBER OPTIC BEAM-IMAGING APPARATUS WITH PLASTIC REDUCER BUNDLES AND METHOD

Field of the Invention

This invention relates to diagnostic imaging devices. More particularly, it relates to such imaging devices for producing a real-time image from a high-energy irradiating beam directed through an object. In other aspects, this invention relates to tapered cross-sectional area plastic fiber optic elements, and a system and method for their fabrication as well as a system and method for forming clad plastic preforms from which they may be fabricated.

Background of the Invention

This invention is particularly well suited to external beam treatment verification, low-energy

x-ray diagnostic applications, and quality assurance in radiotherapy. The discussion and description which follows is specifically directed to this application. However, it will be understood that the invention is also applicable to other imaging systems, such as imaging mechanical parts for quality control or inspection. Other applications presently using film to image x-ray or charged particle beams are also applicable.

In radiation therapy, a beam modifying block which absorbs the treating radiation is placed between the patient and the radiation source. This block has an aperture or port which allows the radiation to be directed directly at the patient in a limited treatment region. Errors in the placement of the port or the alignment or intensity of the radiation source can result in suboptimal treatments. It is therefore desirable to obtain feedback on the location of the port and on the actual dose of the radiation applied to the patient.

Conventional feedback is provided by the use of radiographic film exposed for a short initial duration for localization, or for the entire duration of treatment for verification. This is a popular method because conventional treatment tables have a space usually limited to four to six inches between the platform on which the patient lies and the radiation-absorbing shield or beam stopper disposed opposite the radiation source to absorb the radiation extending beyond the patient.

The use of radiographic film has several limitations. Among them is that the resulting image is of poor quality. Further, a significant amount of time is involved in the processing of the exposed film to produce an image of the treatment radiation,

as well as the time required by the treating physician to study the film, before deciding on what corrective or compensating action should be taken. In the localization mode, the approach cannot ensure that there is no further misalignment during treatment. Certainly, in the verification mode, if the imaged treatment involved errors, those errors already exist and cannot be neutralized. This deficiency is further compounded because the portal film verification process usually limits such a procedure to once a week. It is thus desirable to provide real-time feedback so that any desired corrective measures can be taken rapidly to avoid exposing the patient to a full treatment radiation dosage that is incorrect.

Several such systems have been proposed or developed. For instance, a real-time feedback system was generally proposed by Hubener et al in "Computed Tomography in Radiotherapy Treatment Planning: Necessity or Pseudo-Accuracy?", British Journal of Radiology, Supplement 15, March 28-30, 1979, pp. 186-189. They suggest the use of a detector array for measuring the absorption of radiation passing through the patient similar to the CT detector system. No specific structure of the detector array is proposed.

Other systems have been more recently proposed. Leong in "Use of Digital Fluoroscopy as an On-line Verification Device in Radiation Therapy", Phys. Med. Biol., 1986, Vol. 31, No. 9, pp. 985-992, discloses a record and verify system which combines a fluoroscopic technique with digital image processing. The system specifically uses an E-2 fluorescent screen to convert x-ray images into light images. The light images are detected by a video camera which receives

the image as reflected by a mirror large enough to image the irradiated area of interest on the fluorescent screen. This system thus requires a substantial amount of space below the patient, where space is not generally available, as has been mentioned. In those treatment machines with beam stoppers, such space is generally not available. Even where there is no beam stopper, the bulkiness of the device renders its adaptation to the treatment machine difficult.

Other systems use an image intensifier tube to generate an optical image for direct viewing by a camera. This system is variously described in U.S. Patent Nos. 4,590,518 issued to Fenster et al for "Arrangement for Processing Data in Digital Fluorographic Systems"; 4,595,949 issued to Fenster et al for "Systems and Methods for Translating Radiation Intensity into Pixel Values"; and 4,649,559 issued to Wang for "Digital Radiography Device". These systems show the placement of monitoring devices in line with the radiation source and patient, thereby also requiring a substantial amount of space for imaging.

Examples of prior art which are related to the same problem are shown in U.S. Patent Nos. 3,058,021 issued to Dunn entitled "Optical Coupling Device Between X-Ray Intensifier and Vidicon Camera Tube or the Like"; and 4,593,400 issued to Mouyen entitled "Apparatus for Providing a Dental Radiological Image and Intra-Oral Sensor Used Therewith". The Dunn reference discloses an improved optical system for coupling the x-ray image formed on a fluorescent screen to a television camera or other image utilizing apparatus. In one embodiment as shown therein, the coupling unit is comprised of a bundle of slender filaments of glass, i.e., individual fiber optic elements, which have one end connected to the image form-

ing fluorescent screen of the intensifier and the other end to the light sensitive surface of the camera. Dunn suggests that the bundle may be curved and tapered with a smaller output end disposed outwardly of the path of all stray x-ray radiation, but does not suggest any particular method or means for achieving the taper or curve. Additionally, the reduction between the output end and the input end is not particularly mentioned but apparently is on the order of 4:1 or the like.

The Mouyen reference discloses an x-ray sensing device for sensing the x-ray image created by x-rays passing through an irradiated tooth and converting them into visible radiation. It includes a screen having a scintillating material deposited thereon with a plurality of reducing optical fibers for transmitting the visible radiation to an electronic processing unit for displaying the image of the tooth on the monitor of a display system. The optical fibers utilized are disclosed as preferably being made of stabilized glass and the coupling unit itself provides a reduction of 4:1 from output to input.

As mentioned above, both of these prior art references disclose fiber optic coupling units which may be formed into a right angle, but which are comprised of individual glass fibers such that the bundles are quite expensive and have limitations in their reduction and density. Furthermore, not only is the cost of the individual fiber expensive, but it is quite expensive to individually form the fibers and then arrange them in correlated arrays such that there is a correspondence between the input surface and the output surface to permit accurate imaging from one end of the coupler to the other. In other words, the

individual fibers have to be very carefully arranged in arrays which correspond in position at their input and output ends, and then fused or otherwise secured in that fixed array. As can be appreciated, for high density packing, this process can be quite time-consuming, expensive, and require complicated manufacturing equipment to be specifically designed for that purpose.

Summary of the Invention

It is one general object of the invention to provide apparatus which overcomes the above-mentioned limitations in x-ray and other high-energy imaging procedures.

A more specific object of the invention is to provide such an apparatus which is compatible with the limited space available in typical x-ray treatment machines and the like.

Yet another object of the invention is to provide such an apparatus which can also be designed for low-energy x-ray diagnostic applications.

Providing a novel plastic fiber-optic assembly which can be formed at 16:1 reduction for use in such an apparatus is yet another object of the invention.

The method of making the novel plastic fiber optic reducer assembly from a multi-fiber boule, the method of purifying the styrene by distillation and forming the raw preform, and the multi-fibers themselves are still other objects of the invention.

The apparatus of the invention is used in generating a reduced-scale optical image of a beam pattern produced by directing a high-energy irradiating beam, such as a gamma or x-ray, through an object along a predetermined path. The apparatus includes an assembly of plastic optical fibers which

have input end regions disposed in a two-dimensional input array which encompasses the area of the beam pattern, and output ends which are disposed in a reduced-scale two-dimensional output array. A beam converter in the apparatus functions to convert the irradiating beam which passes through the object to an electron beam whose density distribution is directly related to the impinging irradiating beam. This electron beam is converted to a pattern of visible light which is carried by the fibers to their output ends, to form a reduced-scale image of the irradiating beam pattern.

In one embodiment the individual fibers in the array have tapered cross-sectional areas, on progressing from their input to output ends, and are arranged so that the fiber input ends form the input array, and the fiber output ends, the output array. Preferably, the fibers are formed of optically conductive polymer. In a preferred embodiment, the fibers are arranged in groups of fused fibers, tapered, forming optical reducers, each having input and reduced-area output ends. The reducers, which form another aspect of the invention, are then arranged to form the fiber arrays in the fiber assembly.

In a related embodiment, for use in generating a high-resolution image of the irradiating beam, the optical fiber assembly is formed as an array of reducers, as above, and the reducers are formed as an array of fiber bundles. The fiber bundles, in turn, are each formed as an array of optical fibers. The array of fiber bundles making up each reducer are drawn and tapered, in fused form, to produce a reduced cross-sectional area on progressing from the reducer's input to output end.

In the above embodiments, the beam con-

verter includes a metal plate which covers the input array. The electron beam is converted to a corresponding light beam by a fluorescent screen disposed between the metal plate and the array.

In a second general embodiment, the input array in the optical fiber assembly is formed by longitudinally extending input regions of the planar array of parallel fibers, adjacent the input ends of the fibers, and the output array is formed as a two-dimensional array of the output ends of the fibers. The beam converter includes a metal strip extending across the end regions of the fibers, substantially transversely thereof, for converting associated strip regions of the irradiating beam to strip regions of electron beams. The electron beam strips are converted to corresponding light intensity signals in the fibers by (a) a fluorescent screen strip disposed between the metal strip and the two-dimensional input array, for converting the strip regions of electron beams to a first-wavelength radiation beam strip, and (b) a fluorescent dye contained in the input regions of the fibers, for converting the first-wavelength radiation beam strip to a visible light within the fibers. The metal strip and fluorescent screen strip are moved as a unit along the length of the fiber input region, to generate in the fiber input region of each fiber, an instantaneous light intensity which is directly related to the intensity of the irradiation beam which is impinging on the metal strip in the region between the beam and that fiber.

This embodiment further includes an image processor for generating from the instantaneous light intensity received at the output of each fiber, as the metal strip and fluorescent screen are moved along the lengths of the fiber input regions, a two-dimensional

optical image corresponding to the intensity of the irradiating beam impinging on the two-dimensional input array.

In a third general embodiment, the input array in the optical fiber assembly is also formed by longitudinally extending input regions of a planar array of parallel fibers, and the output array, as a two-dimensional array of the output ends of the fibers. The beam converter in this embodiment is a metal plate covering the input array, for forming a related electron beam, and this beam is converted to light signals in the optical fibers by one or more fluorescent species in the fibers. To generate the image of the irradiation beam, the input array is rotated with respect to the irradiated object, and the instantaneous light intensity signals from each fiber, as the fiber array is rotated with respect to the object, are processed to construct the desired image.

In other aspects, this invention provides a method for manufacturing tapered plastic fiber optic bundles or reducers of the type used herein, as well as the multi-fibers themselves. These reducers or bundles include an assembly of plastic optical fibers, each tapered so as to have a larger cross-sectional shape at one end of the reducer, as compared to the cross-sectional shape at the second end of the reducer. This process includes a first step of securing a preform which consists essentially of an assembly of optical fibers having cross-sectional shapes corresponding to the cross-sectional diameters of the optical fibers at the first end of the reducer. Generally, this securing step places the preform in a vertical position. The second step involves applying heat to a bottom portion of the length of the preform

with a movable heater element. An end-to-end tension is applied to the preform. When the heating reaches the point that the bottom of the preform becomes plastic, the bottom portion drops down and the connective multi-fiber is placed between a pincher wheel assembly. The motorized wheel is turned on at a rate to draw a fiber of predetermined size. The tension is maintained constant so as to taper the preform through the heating zone and draw a fiber having the desired smaller second cross-sectional diameter from the preform. The movable heater is moved along the preform to obtain the desired fiber shape and tapered fiber optic reducer. Once this is formed, the heating element is withdrawn from the preform, with end-to-end tension maintained, and the fiber optic reducer is allowed to cool.

The preforms which are formed into the taper are preferably themselves bundles of clad fibers, such that when the taper is formed, a plurality of fibers are themselves tapered. In preferred embodiments, each of these fibers is a clad fiber. That is, each fiber comprises a core surrounded by a concentric outer coating. In another embodiment of this invention, these clad preforms are formed. Preferably, this outer coating is continuous around the core when viewed cross sectionally. In another embodiment of this invention, clad preforms from which these clad fibers are made, are formed. In this embodiment, these clad preforms, which comprise a core surrounded by an outer coating, are formed. The core generally comprises an optically pure transmissive plastic material and the cladding comprises a second plastic material generally of lower index of refraction than the core material. These cladded preforms are generally in the form of billets and are formed in a

cladding oven by a unique process. The purity of the core material has been found to have a significant impact on the transmissibility of the core. Core material having a purity of 99.999% has been used with good results.

The inventors have developed a method for creating core material having the purity required to form fibers with the method as disclosed herein. This method comprises the steps of processing commercially available styrene monomer and then straining this styrene monomer through a glass column filled with de-inhibiting beads to remove the inhibitors present in the commercial styrene. With the inhibitors removed, the styrene is next distilled. To increase the throughput of the distillation process, a negative pressure of 3 millibars is placed on the distiller. The distilled styrene is then placed in molds in liquid form and heated in an oven to achieve polymerization. At present, an aluminum foil liner is used inside of an aluminum tube for forming the raw core material as the aluminum foil has been found to effectively isolate the styrene from the aluminum tube to facilitate its separation from the raw core after polymerization. The raw core may then be machined, as desired and cladding applied to the core. As explained more completely in the detailed description, the thickness of the cladding must be maintained within certain limits in order to ensure good performance of the fibers which are drawn from this primary core.

The process of forming multi-fiber preforms includes a first step of stacking individual plastic optical fibers into a matrix, such as 16 x 16; wrapping the matrix with Teflon™ and inserting the matrix into a full length aluminum tube. The aluminum tube

and matrix is then fused by firing it in a vacuum oven. This fused matrix of individual plastic fiber optic elements is then removed from the oven, the original Teflon™ wrapping removed, and then rewrapped with a Teflon™ film, placed inside a second fusing tube having much closer tolerances to the size of the matrix, or preform, and then fired a second time to thereby form a multi-boule. After this second firing, the multi-boule is comprised of a length of individual fibers arranged in a 16 x 16 matrix and which is suitable for further processing. This multi-boule is then placed in the fiber optic drawing device disclosed herein to form a reducer having up to a 16:1 reduction from its input end to its output end. Thus, this process is used to form multi-fiber boules demonstrating a 16:1 reduction. Additionally, the multi-fiber boule previously described may itself be used to produce fibers of approximately the same size as the individual fibers which formed the first multi-fiber boule. These multi-fibers may then be used to repeat the same process as described above by being placed in a 16 x 16 matrix, fired through two separate processes, and then drawn to form a 16:1 reducer comprised of a 16 x 16 matrix of multi-fibers, each multi-fiber itself being comprised of a 16 x 16 matrix of individual fibers.

Taking this one step further, the multi-fiber reducer may be used to form still a third fiber which can be used in the process to produce a multi-fiber reducer formed of a 16 x 16 matrix of arrays, each array being itself formed of a 16 x 16 matrix of arrays of individual fibers. With this process, a first multi-boule formed of individual fibers may have fibers of 1.52 mm dimension. With a second processing as described herein, the individual fibers

are reduced to 95 microns per side. If a third step through the process is utilized, the finished reducer is comprised of a plurality of fibers each of which is 5.95 microns a side. Thus, by repeating the drawing process and refusing the fibers into multi-fiber arrays, the resolution of the reducer may be dramatically improved by effectively decreasing the pixel dimension.

Not only does this process result in plastic fiber optic reducer bundles having a 16:1 reduction, which is itself presently prohibitively expensive for large arrays in glass fibers and hence commercially unavailable, but this is achieved in a plastic medium having much lower cost with a significantly easier manufacturing process and with resolution comparable to those glass fiber optic elements produced at significantly greater expense.

These and other advantages and features of the invention will be apparent from a review of the drawings and the following detailed description of the preferred embodiment.

Brief Description of the Drawings

Figure 1 is a schematic side view of an imaging system including an apparatus made according to the invention;

Figure 2 is a perspective view of an optical fiber assembly constructed according to the invention;

Figure 3 is a perspective view of an optical fiber reducer from the Figure 2 assembly;

Figure 3a is an enlarged perspective view of a typical clad optical fiber reducer from the Figure 2 assembly;

Figure 4 is a fragmentary perspective view of a fiber bundle used in forming a high-resolution reducer;

Figure 4a is an enlarged perspective view of a fiber bundle formed of clad fibers;

Figure 5 is a partial view similar to Figure 1 showing a second preferred embodiment of the invention;

Figure 6 is an enlarged fragmentary perspective view of the apparatus of Figure 5;

Figure 7 is a further enlarged fragmentary perspective view of a portion of the apparatus of Figure 5;

Figure 8 is a cross section taken along the line 8-8 in Figure 7;

Figure 9 is a simplified fragmentary view of the output end of the transmission optical fiber array of Figure 5;

Figure 10 is a simplified perspective view of a third preferred embodiment of the invention;

Figure 11 is a frontal view of a system for drawing tapered fibers;

Figure 12 is a frontal view of a mechanism for moving the oven which makes up part of the system shown in Figure 11;

Figure 13 is a series of views of a vacuum fixture in exploded "story board" format, illustrating its assembly for use in preparing clad billets of preform material for forming tapered fibers;

Figure 14 is a frontal view of an apparatus useful for forming the clad billets of material which incorporates the vacuum fixture of Figure 13;

Figure 15 is a perspective view of a fiber array formed into a taper in accord with the invention;

Figure 16 is a side view of a plastic fiber optic boule which has deformed in the process of drawing fibers therefrom;

Figure 17 is a side view of a glass fiber optic reducer;

Figure 18 is a side elevational view of a de-inhibiting column used to separate the inhibitor from styrene monomer;

Figure 19 is a side elevational view of a distiller used to distill styrene;

Figure 20 is a side elevational view of an aluminum tube used for forming the raw preforms;

Figure 21 is a cross-sectional view of a raw preform wrapped in aluminum foil inside of an aluminum tube;

Figure 22 is an elevational view of an oven with a plurality of aluminum forms placed therein for heating; and

Figure 23 is an elevational view of a raw preform after polymerization into a solid.

Detailed Description of the Invention

Referring initially to Figure 1, an apparatus 20 made according to the invention is shown schematically in a radiotherapy system 22 for treating a patient 24. System 22 includes a source 26 of x-ray radiation directed during treatment along an incident beam path 28. The irradiating beam, indicated at 29, may also be a gamma-ray or other high-energy radiation beam. Although it is not shown, a radiation block is normally placed over the patient. The block has a port which allows a limited cross-sectional area of the radiation to pass into and through the patient. The alignment and dosage of the treatment is obtained by sensing the intensity distribution of the beam after it has passed the patient.

The patient is typically disposed on a bed or platform 30 below which is a limited amount of space for positioning sensing or imaging equipment.

The image-sensing and reduction portions of apparatus 20, shown enlarged in Figure 1, will fit within this space. The apparatus includes a light-tight box 32. Disposed along a surface portion of the box is a plate-like beam converter 34, conventionally made of a sheet or foil of metal, such as lead, copper, brass, or other heavy metal, which converts the impinging irradiating beam into electrons, and therefore in essence, into an electron beam having an electron density distribution directly related to the intensity distribution of the incident beam.

The electrons created in the photon conversion reactions produce light in a sheet-like, fluorescent screen 36. This screen is preferably about 0.1 mm thick, but can be up to 1 mm or greater in thickness. The preferred screen has an active rare earth phosphor such as $Gd_2O_2S:Tb$. Other phosphors which would be suitable are $La_2O_2S:Tb$ or $CaWO_2$. These fluorescent screens can be purchased from Eastman Kodak Co. Alternately a sheet of plastic scintillator can be used instead of the screen to give light output closely related to the dose in water. This could be very useful for dosimetric verification or quality assurance purposes. These plastic scintillators are commercially available from companies such as Bicron of Cleveland, Ohio and Nuclear Enterprises of Scotland. Screen 36 is also referred to herein as means for converting the electron beam produced by the converter to a pattern of visible light which is directly related to the irradiation beam impinging on the beam converter. The top surface 36a of the fluorescent screen, as viewed in the figure, is disposed adjacent the lower surface of converter 34. The bottom surface 36b confronts the input end of an optical fiber assembly 38, which

will now be described.

As seen best in Figure 2, fiber assembly 38 is formed of an n x m image array of fiber reducers, such as reducer 40, which is detailed in Figure 3. Although the assembly illustrated forms a rectangular and preferably square input and output square array, it will be appreciated that a variety of other input and/or output array shapes, such as an oval or circular array, are possible. The assembly has an input end 42 whose area encompasses the area of the beam pattern, and a reduced-scale output end 44 whose area is preferably about 1/256 of the area of the assembley's input end. The assembly functions to carry the light image formed by screen 36 to a location remote from the screen, where the image output is in reduced scale. As seen in Figure 1, assembly 38 has an approximately right-angle bend between its input and output ends.

With reference now to Figure 3, reducer 40, which is exemplary, is formed of a j x k fiber array of optical fibers, such as fibers 46. The fiber reducer is produced, in accordance with one method, by first forming a j x k image array of uniform-area optical fibers, e.g., square optical fibers 46 whose sides are between about 1-2 mm, and having lengths between about 25-100 cm. Such fibers may be formed, for example, by drawing out relatively large-dimension square optical light pipes or preforms to the desired uniform cross-sectional size. The total number of fibers forming the fiber array is preferably between about 100-600, and a preferred array is a 16 x 16 square array, i.e., having 256 fibers. This array, with 1.5 mm square fibers, would thus have side dimensions of about 2.4 cm, and a surface area of about 5-6 cm^2.

The fiber array is then wrapped with a Teflon™ wrapping of approximately .002 inches and inserted into an aluminum tube having an inside area substantially the same as that of the wrapped array. A number of tubes containing wrapped arrays are then placed in a vacuum oven and heated to elevated temperatures in a vacuum in order to fuse the fibers into the preform or boule. The amount of time and temperature for this first fusing step in a vacuum oven varies with the size of the individual fibers used to form the arrays as well as the number of tubes containing arrays which are placed in the oven. For arrays comprised of fibers measuring .058 inches, a first or "swelling" step may be utilized wherein the fibers are double wrapped with Teflon™ having a dimension of .002 inches and then the arrays are heated at 65°C for a half hour, 85°C for a half hour, and 65°C for a half hour in order to swell the individual fibers to form a boule having the same cross-sectional area as those with the larger fibers. After this "swelling" step, the arrays of .058 inch fibers are processed through the first fusing step as described herein. An example of a first fusing is for 12 arrays of fibers measuring .059-.061 inches which can be fused at 65°C for a half hour, 85°C for a half hour, 100°C for a half hour, 125°C for one hour and twenty-five minutes, and cool down to 65°C.

After each array or boule has been first fused in a vacuum oven as described above, they are removed from the aluminum tubes and the original Teflon™ wrapping removed. They are then individually wrapped with a Teflon™ wrap measuring .0005 inches. The wrapped boule is then placed inside an aluminum fixture having a substantially stronger construction than the aluminum tubes used in the first fusing. The

next step in the process involves a second firing or fusing of the boules. For four such boules, they may be heated at 69°C for a half hour, 147°C for one and a half hours, and then 69°C cool down. For 12 such arrays, this step involves heating the boules to 69°C for a half hour, 147°C for two and three-quarter hours, and 69°C cool down.

An alternate method for this second fuse is to use only the first aluminum tube. After the initial fuse the multi-boule is re-wrapped with .0005" Teflon™ followed by a wrapping of .001" Mylar. Using this method results in a lower second fuse temperature or a shorter heating time to accomplish the same purpose as the first method.

The fused unit is now preferentially heated along its length so that when drawn out, it will have a progressively reduced cross-sectional area on progressing from one end to another, and more particularly, from a larger input end 48 formed by the input ends of the fibers making up the reducer, to a smaller output end 50 formed by the output ends of the fibers. If the process disclosed herein which provides for both a first and second fusing is not followed, the plastic boule deforms by swelling into a bulbous shape much as is depicted in Figure 16. As indicated above, the area of the output end is typically 1/256 of the area of the input end. In one preferred embodiment, the input end has an area of about 6 cm^2, and the output end, an area of about 0.06 cm^2.

The reducers are individually bent and then fitted together to form the assembly. It can be appreciated from Figure 1 that the individual reducers forming each "column" of the fiber assembly will have different lengths.

The fibers of the reducers have a turning

radius of about 5 cm. The numerical aperture of the "untapered" portion of each optical fiber is .57. Because the fiber width at the output region has been substantially reduced, this cone of transmitted light will actually be much smaller, e.g., about 2 degrees when the output end fiber width is about one-tenth that of the fiber input end. Thus, besides providing for substantial space reduction, the fiber reducers also act as collimators to admit only that light that is entering essentially normal to the fiber ends. Thus, there is little blurring of the resultant image due to crossover of the light between scintillator regions defined by the fiber inlet ends.

A fraction of the scintillation light produced above each fiber is light piped through the fiber reducers, the output of which is viewed by a lens 52. When the screen or plastic scintillator sheet produces light in the green-red spectral region, a blue filter 54 is preferably placed between the output end of the assembly and lens 52 to filter out unwanted background light which is predominantly in the blue region of the visual spectrum.

The lens couples the optical signal transmitted through assembly 38 to a video camera 56. Figure 1 shows light rays from the fiber assembly passing through filter 54, lens 52 and into camera 56. To improve performance, an optical joint is used between the assembly 38 and lens 52, and between lens 52 and camera 56. The optical joint is formed with an index matching cement such as silicon rubber or epoxy. The camera may be of the conventional vidicon, CCD or CID type. Further, instead of using a lens, the image may be coupled to the camera by proximity focusing, wherein optical fibers from a fiber optic coupler are placed directly on the fiber re-

ducer array 38 at one end and onto the sensor array of the camera at the other end, or by coupling the output end of the fiber assembly directly onto the camera sensor array.

The camera output is digitized, processed by a small computer or microprocessor 58 using conventional video signal processing programs such as that described in the prior art for signal generation and enhancement, or such as that sold under the proprietary name of Data Translation Frame Grabber. The digitized signal from processor 58 is displayed on a monitor 60, and is stored in the image processor memory for later use. This resultant image is available within a few seconds from the time the incident irradiation beam is directed through the subject.

In applications requiring resolution of very low contrast images, cross-talk between fibers may degrade the resolution. Cross-talk can be prevented, in one embodiment, by making alternate fibers out of non-transmissive, i.e., black plastic. This prevents light from traveling between adjacent light-transmissive fibers. However, this approach inherently cuts down on the sharpness of the resulting image, since half the image information is removed. To some extent this loss may be compensated for by image-enhancing software that is available.

An alternative approach is to coat each optical fiber with a second cladding of non-transmissive material, e.g., black plastic. Here each optical fiber will have a clear, light-transmissive cladding, and an outer dark, non-transmissive cladding. The non-transmissive cladding can be formed conveniently on the large-dimension optical fiber which is drawn to form the relatively small-dimension fibers used in forming the individual reducers. Although this is a

more expensive solution, it allows more of the scintillation light to be transmitted.

Figure 3a shows how each fiber 46, 46A, etc. in reducer 40 can be formed with a cladding 45 and core 47, if desired.

A second source of resolution degradation which occurs is low level scintillation and/or Cherenkov emission resulting from electrons penetrating into the fiber reducer. This background can be greatly reduced by using an optical filter 54 as mentioned above. If proximity focusing is used, this filter must be very thin, of the order of 0.1 mm. If significant background is present, the fluorescent screen or plastic scintillator is chosen as mentioned such that it emits in the green-red region of the optical spectrum. Since the scintillation and/or Cherenkov background emitted from the fiber reducers is predominately in the blue, a long wavelength pass filter which filters out blue light effectively reduces the background from these sources.

Further background reduction can be attained by blackening the large input end of several fibers in each reducer, such as illustrated in Figure 3, which shows fiber ends 62. The darkened ends effectively block light transmission in the selected fibers. This provides in those optical fibers, a light signal which represents the background light being produced in and transmitted by the "clear-end" fibers. The image processor is designed to distinguish between the two and to subtract the background light from that produced in the active fibers.

A further alternative approach for obtaining background levels for the embodiment shown in Figure 1 is to take an image when beam 29 is not being transmitted. This reading then represents the

electronic system background, or non-radiation induced background. Radiation-induced background can also be measured by removing the scintillator screen when the beam is being transmitted and to use this as the background signal. Conventional digital image enhancement programs can readily subtract the background frame from the active signal frame to eliminate the background. These alternatives allow all of the fibers to transmit a beam image signal.

Figure 4 shows a portion of a reducer 64 designed for a fiber assembly capable of high-resolution imaging of a radiation beam. The reducer is formed of a j x k array of fiber bundles, such as bundle 66, where each bundle has approximately the same dimensions as the individual fibers in the above reducer 40. More particularly, a preferred reducer contains between about 100-600 fiber bundles, and each bundle has an input end which is about 1.5 mm on a side, and an output end which is about one-tenth that dimension.

With continued reference to Figure 4, bundle 66, which is representative, is composed of a c x d array of optical fibers, such as fibers 68. To form a fiber bundle, the optical fibers, which are preferably square fibers about 1-2 mm on a side, are arranged in a desired array, such as a square array containing between about 100-600 fibers, and these are fused as above. The fused block is then drawn down to a very small cross section, preferably about 1-2 mm on a side. The bundles, each of which contains between 100 and 600 individual fibers, are then combined to form a j x k bundle array which will, in effect, substitute for the individual fibers used in forming reducer 40, to increase the total number of optical fibers in the reducer, and therefore the re-

ducer resolution, by a factor of 100-400. The reducer 64 can be drawn once more to form the individual fibers for still another reducer, thereby forming an array of arrays, with still greater resolution. Of course, the fiber bundles could be composed of a smaller number of fibers, such as 5-100 fibers, which would produce a corresponding decrease in the total number of reducer fibers.

If desired, the fibers in the bundle may be clad so as to give a configuration as shown in Figure 4a.

A second preferred embodiment of the invention is shown in Figures 5-9. In this embodiment, an optical image-generating apparatus 70 has a light-tight box 72, a strip photon converter 74, or beam converter, a fluorescent strip 76, a fiber assembly 78, a lens 80 and a video camera 81. The microprocessor and monitor are eliminated for simplicity of illustration.

The fluorescent strip 76 consists, in one embodiment, of a linear array of short segments of plastic fluorescent optical fibers 77 which are positioned to extend preferably normal to input regions of the fibers in assembly 78. An enlarged fragmentary portion of the strip is seen in Figure 7. The fiber segments making up the strip contain a primary fluorescent dye with a fluorescent emission in the ultraviolet or blue in response to the electrons generated in the strip itself and by the strip photon converter 74 placed directly above the fluorescent strip 76. The segments are nominally 1 mm^2 in cross section and 1-5 mm in height. The fluorescent strip could also be made of a thin strip of fluorescent screen as described in the first embodiment. In this case a 1 mm x 40 cm strip of fluorescent screen

would be located directly below the strip photon converter, as was the linear array of scintillating fibers.

The fiber assembly is composed of an array of optical fibers, such as fibers 82, and preferably square polymer fibers having side dimensions of between about 1-2 mm, as above, although other cross-sectional shapes and dimensions may be suitable. An enlarged fragmentary portion of the assembly is seen in Figure 7. The fibers are arranged at their input regions in a parallel or side-by-side planar array, such that longitudinally extending input regions of the fibers, such as input regions 84, form an input array 86 whose area encompasses the area of the irradiation beam. The fibers are arranged at their output ends in groups of stacked fibers, as shown in Figure 6, which form a two-dimensional array of fiber output ends. In a preferred embodiment, the total number of fibers forming the input array is between about 100-1,000, where the width dimension of the individual fibers is preferably between about 1-2 mm.

A two-dimensional output array 88 (Figure 9) in the assembly is formed by stacking groups of the optical fibers in an n x m arrangement, as indicated in Figure 6. For example, where the assembly consists of 400 fibers, 1 mm in cross section, the output array can be formed by stacking 20 groups of 20 planar fibers, to form a square 20 x 20 fiber array. The fibers are preferably not tapered between their input and output end, so that the side dimension of the output array is 2 cm in this example.

The fibers forming the assembly are doped with a secondary or "waveshifter" fluorescent dye which responds mainly to light emitted from the fluorescent strip 76. The secondary dye is chosen so

that its absorption band is well matched to the emission band of the fluorescent strip and so that it re-emits this light at longer wavelength.

The fluorescent strip 76 and overlying converter strip are mounted at opposite ends to frame 90 and supported on a movable carriage and driver (indicated by arrow 96, which indicates the back-and-forth directions of movement of the two strips across the input array). The driver and movable carriage, which are entirely conventional, are also referred to herein as moving means.

During operation, the two movable strips travel as a unit across the input array of the fiber assembly, with the fluorescent strip emitting a light-beam strip, in response to excitation by electrons, which is then absorbed by the dye in the assembly fibers, as indicated in Figure 8. This dye acts as a waveshifter to emit isotropically the desired light, a portion of which travels down the secondary fibers to the fiber output 88. It will be appreciated that the fibers in the fiber assembly need to contain internal fluorescent doping material in order to convert a portion of the light emission striking the fibers at substantially right angles into light that will propagate within the fibers.

Summarizing, the fluorescent screen strip functions to convert the strip regions of electron beams produced by the beam converter into a first-wavelength radiation beam strip. The secondary fluorescent dye in the assembly fibers functions to convert the first-wavelength beam strip into visible light emissions within the fibers. The moving means functions to move the metal strip and fluorescent strip as a unit along the lengths of the input regions of the assembly fibers, to generate the fiber

input regions, an instantaneous light intensity which is directly related to the intensity of the radiation beam which is impinging upon the metal strip. The fluorescent screen, secondary fluorescent dye, and moving means are also referred to herein as converting means for converting the electron beam image produced by the irradiating beam into a reduced scale optical image.

The data obtained with the fluorescent strip 76 in a single x position gives a linear array of y values. The fluorescent strip is swept along the length of the fibers in array 86--i.e., along the x axis. To obtain 1 mm resolution, data must be taken at 1 mm intervals.

As with the first embodiment, the resolution of low contrast images may be degraded by background scintillation caused by electrons or x-rays traversing the assembly fibers, thus giving a signal in addition to the signal from the fluorescent strip resulting from the incident beam. This background can be determined by optically isolating several of the fibers in the secondary fiber array from emission from the primary scintillator strip. This can be done by applying a black coating to the outside of these fibers. The output of these fibers can be read out and subtracted from the secondary fiber signal, thus removing the background. A second method for removing background is to remove the scintillator strip and expose the remaining apparatus to the radiation beam. This background signal can then be subtracted from the total signal as in the first embodiment.

In some applications, the second embodiment of this invention can be simplified by leaving out the fluorescent strip, and simply scanning the con-

verter strip 74 along the assembly fiber input regions. This would require the addition of both primary and secondary dyes to the core material in the fibers. All other aspects of the instrument remain unchanged. As the converter is scanned across the assembly fiber input regions, the radiation beam will be converted into electrons in the converter, thereby resulting in enhanced excitation of the scintillator immediately below the converter. Here the converting means would include the primary and secondary dyes contained in the assembly fibers, as well as the above moving means.

Reference is now made to a third embodiment of the invention as shown in Figure 10 without relation to a patient or x-ray beam. This embodiment, shown as an apparatus 110 which substitutes for apparatus 20 in Figure 1 or apparatus 70 in Figure 5. In fact, this embodiment is more closely similar to that shown in Figure 5. It includes a planar fiber assembly 112 whose optical fiber arrangement is substantially identical to that of assembly 78 in apparatus 70. In particular, assembly 112 includes an input array 113 formed by the input regions 115 of the fibers in a parallel side-by-side configuration, and an output array 122 formed by stacking groups of fibers. Assembly 112 differs from assembly 86, however, in that the fibers 114 making up the assembly contain both the above primary and secondary fluorescent dyes. It it to be understood that a sheet-like photon converter would also be disposed above this assembly, preferably in a fixed position so that the electrons produced are directly relatable in physical position to the impinging x-ray beam.

The output array of assembly 112 is coupled to a digital camera as described for the embodiment

of Figure 5. The output array is divided into groups, such as group 120, for forming a rectangular output array 122 for viewing by a camera 126, through a lens 127. These components are mounted on a turntable 128 controllably driven, by suitable moving means (indicated by arrow 129) for rotation about a vertical axis 130.

For a single location of the ribbon, the signal obtained from each fiber is the line integral, or sum, of the signal resulting from penetration of the beam all along each fiber. The entire scintillator array - camera system is then rotated about axis 130. Data is acquired at many angular orientations. Algorithms such as those used for computed tomography scanners would provide image reconstruction.

The converting means in this embodiment thus includes the primary and secondary fluorescent dyes in the assembly fibers, and the moving mass for rotating turntable 128.

It will be appreciated that variations may be made in the foregoing embodiments without departing from the scope of the invention. In particular, it will be appreciated that the device can be readily adapted for imaging a particle beam. Here, since the beam particles can produce direct scintillation of a primary fluorescent dye, the beam converter in the above-described embodiments would not be required.

The tapered fiber optic fibers or bundles useful in this invention can be prepared from preforms in a novel manner using the apparatus 200 shown in Figure 11. Unlike prior art processes, the invention process involves holding the fiber preform in a fixed position and moving a heater element gradually along the preform to melt it. Presently available

machines used to draw optical fibers from preforms generally employ a flexible chain which lowers the preform into an oven. This system is inherently incapable of reliably positioning the preform. Reliable positioning is necessary to insure even heating. The presently available systems also do not provide for constant tension on the fiber during heating.

The present method and system involve holding one end of the preform in a fixed position while pulling on the other end of the preform while sliding an oven along the preform's length. This permits tension to be applied to the preform and further allows a steady positioning of the preform and resulting fiber in the heating zone.

A general overview of the fiber optic forming apparatus 200 is shown in Figure 11. The fiber optic substrate is preform 204. Preform 204 has a larger cross section at one end and is drawn to the fiber optic 204a of reduced cross section. The preform is held at one end by an XYZ positioning device 207. The other end of the preform extends through a heater/oven 211. The oven softens the preform such as at a temperature of about 250°C. This softening allows the preform to stretch into a prefiber and the lower portion of the preform to drop down. When this happens the connective fiber link is placed into a pinch wheel assembly, the motorized wheel is turned on. The lower portion of the preform drops off as shown at 203 leaving the fiber of reduced diameter 204a.

The preform can be a two-component material comprising a center core and an exterior cladding. In a preferred embodiment, it can be a multifiber preform made up of a plurality of prefibers bonded together. In a preferred embodiment, each of the pre-

fibers is 1.5 mm square. These prefibers are formed into a solid preform rod referred to as a multi-boule.

In operation, after the lower part of the preform drops off, as shown in 203, the fiber optic (preferably multifiber fiber optic) of reduced diameter 204a is placed in the pinch wheel assembly pulling device and the motorized wheel is turned on, the turning rate determining fiber size. The oven positioning device shown in Figure 12 moves the oven gradually away from the pinch wheel drive 205. This causes new regions of the preform to soften by the heat of the oven. The pinch wheel drive 205 draws out the softened preform into a taper and into the fiber of reduced shape 204a. By controlling the temperature of the oven, the speed at which the oven is moved along the preform and the speed at which the pinch wheel drive pulls the fiber from the softened area, the size of the fiber approaches the desired fiber optic size. The oven 211 is caused to move away from the pulling device 205 on rods 210 and 210A. This movement is very slow to maintain a constant supply of plastic fiber optic preform in the heater region. Preferably the device keeps a constant tension through the pinch wheel drive of the fiber. The caliper 212 monitors the resulting fiber size, and the drawing speed is varied until the desired size is obtained. When the desired size is obtained, the oven 211 is lifted vertically out of the drawing region. The preform is left to cool in this configuration while the fiber is held under tension. Cooling is facilitated by passing a stream of cool forced air into the taper region. The resulting tapered reducing fiber optic is then removed from the oven.

As shown in Figure 11, in a preferred embodiment, the various elements are arranged vertical-

ly. In this preferred configuration the preform holding device 207 is mounted above the oven and the pinch wheel drive 205 is mounted beneath the oven. In this configuration, in use, the oven moves upward toward the XYZ positioning device and gravity assists the drawing.

Figure 12 shows a preferred embodiment of a mechanism to effect the motion of the oven. Again, this is shown in the context of upward and downward motion.

The oven fixture slides up and down on slide bars by a pulling device attached to a lead screw assembly driven by a speed controlled D.C. motor. Thus, according to the method of this invention, the multi-fiber preform is held in constant position at one end and under tension at its other end while a heater element is moved along its length to differentially melt a region and form that region into a taper.

The tapered product so formed can appear as shown in Figure 15 as number 46. As can be seen, 46 is a bundle of fibers having large end 42 and small end 44. In practice, this bundle would be cut at the hatch marks to give a new large end 42a which would be polished to an optical surface.

As noted previously, in preferred embodiments of this invention, the individual fibers used herein are cladded. That is, they have a light-transmissive core surrounded by an outer surface which has differing optical properties. Figures 11 and 12 illustrate one way to form these materials from clad preforms or billets. This invention additionally provides a new method and device for forming these cladded preforms or billets.

Turning to Figure 13, a block or load of

optically transmissive plastic 130 is formed, as described below. This block has a defined shape, including a cross section 132 and length L. This will become the core of the cladding material. It is fitted within a hollow sleeve of cladding material 134. The cross section 136 of the hollow opening of sleeve 134 corresponds to the cross section of core 130 so that the core may be slid inside. These dimensions should be closely tailored so that the space between the core and the cladding is relatively minimal. This sleeve with its enclosed core then fits within the void of a hollow aluminum fixture 138. The cross section 140 of this hollow is sized to receive the outside dimensions of sleeve 134. The length L of the core, the length L' of the sleeve, and the length L" of the aluminum fixture are all substantially identical. Fixture 138 may be somewhat longer than the other two components, if desired. Fixture 138 is formed of a solid material capable of good heat transfer and also capable of withstanding substantial positive pressure. Aluminum or other metals are preferred materials of construction. The aluminum fixture loaded with core 130 and sleeve 134 is placed inside closable pressure fixture 142. Pressure fixture 142 has an interior cavity 144 having interior dimensions somewhat larger than the exterior dimensions of fitting 138 so that fixture 138 may fit inside. Pressure fixture 142 is equipped with an O-ring seal and a replaceable door 148, which is sealably bolted to the opening of the fixture, thereby forming an enclosed pressure-tight box separately shown as 150. Pressure vacuum fixture 142 is equipped with pressure rams or plungers 152 and 154. These plungers appear at opposite ends of the fixture and have plunger heads sized to fit into the end cav-

ities of fixture 138. Thus when these two pressure rams move inwardly on their shafts 156 and 158, respectively, they impinge upon and compress the body of sleeving material 134 and core material 130 contained within fixture 138.

Turning now to Figure 14 the use of this cladding fixture in the cladding process of this invention is illustrated. In Figure 14 three pressure fixtures 150, 150a, and 150b are illustrated mounted within oven 160. In use, a vacuum supplied by vacuum pump 162 is applied to the interior of each of the three fixtures. The oven 160 is heated gradually from room temperature to about 125°C. This takes about one hour. After about two hours, the core and cladding materials contained within the vacuum fixtures are heated to a point that they are becoming plastic and flowable. Pressure is then applied to the plungers via shafts 156, 158, 156a, 158a, 156b and 158b via drive units 164 and 166, 164a and 166a, and 164b and 166b, respectively. These drive units can be motorized or can be pneumatic or hydraulic. A pressure is raised to about 1600 psi and should be a slow, steady application of pressure. Preferably, the pressure is increased from about 1000 to 1600 psi over a 3- to 5-minute period. Pressure is held constant at this 1600 lb level for about one-half an hour. The rams may gradually move inward during this period as the two plastics flow and fill. Then the heat is turned off, and the vacuum is turned off. The three vacuum fixtures are allowed to cool to room temperature. No additional pressure is applied and as the system cools, the plastic in the vacuum chambers contracts, thereby automatically releasing the pressure. Thereafter, the vacuum fixtures are opened, the plungers are retracted, and the fixtures such as

138 are withdrawn from the vacuum fixtures. The plastic contained within the fixture 138 may then be removed from the fixture 138. The product so formed is a perfectly concentric core surrounded by a sleeve.

This sleeved product will typically be several inches in cross-section. It can be drawn to some smaller size either to form a single unit preform for tapering or, more preferably, drawn further to a pre-fiber size having a cross-sectional area of about 1-2 mm^2 for forming into a multi-fiber preform.

The cladding conditions just described, are exemplary. Any dimensions which will give rise to a suitable ratio of cladding material to core material may be used. For best results, the cross-sectional area of the fiber should be at least four times the cross-sectional area of the cladding. Also, the minimum effective width of the cladding is 1.5 microns. This dimension provides a practical limit to the minimum fiber size which can be drawn from these particular preforms. Similarly, any shape, for example circular, octagonal, pentagonal, square or rectangular, may be used. Typical forming temperatures can range from about 100°C to about 300°C and maybe higher, if the materials used will permit. So too the forming pressure may range from about 800 psi to about 3000 psi, or preferably from about 1000 to about 2000 psi. Typical forming times may be from about 5 minutes to several hours. Longer times could be used, if desired.

Referring now to Figures 18-23, the distillation and polymerization process for forming raw preforms will be described. As shown in Figure 18, a quantity of commercial grade styrene monomer 200 is filtered by placing it first in a beaker 202 with a

glass tube 204 for drawing the styrene 200 therefrom and into a second, larger glass tube 206 which has a reduced neck 208 at its lower end and which contains a plurality of de-inhibiting beads 208. The styrene is then permitted to flow through glass tube 206 and beads 208 which filter out the inhibitor normally present in commercial grade styrene monomer (as known in the art) such that the inhibitor has been removed from the styrene monomer 210 collected in a second glass beaker 212. Referring now to Figure 19, the beaker 212 containing the styrene monomer 210 may then be used to supply the filtered styrene monomer 210 into a rotary distiller, generally identified as item 214. The rotary distiller may be any rotary distilling device presently available such as a Rotavapor Model R-151. The styrene monomer 210 is fed into a rotating glass beaker 214 and heated to approximately 50°C under approximately 3 millibars of negative pressure at which point it vaporizes, leaving behind the contaminates, impurities, and any other substances other than the styrene monomer. The vapor then condenses on a condensing coil 218 which is refrigerated by refrigerator 220, as known in the art. The filtered, distilled styrene monomer 222 is collected in a collection beaker 224 and is then available for further processing. As shown in Figure 20, an aluminum tube 226 having a substantially square cross-section is used as a mold and, as shown in Figure 21, an envelope of aluminum sheet or foil 228 serves as a barrier between the filtered, distilled, styrene monomer 222 and the aluminum mold 226. The mold 226 filled with styrene monomer 222 is placed in an oven 230 as shown in Figure 22 to accelerate the polymerization of the styrene monomer into a solid. This process is generally achieved at temperatures

between 115°-125°C for 3-5 days. After polymerization has been achieved, a raw preform 232, as shown in Figure 23, is formed and is ready for further processing by machining into a nominal 1-3/4" square. After machining, cladding is applied to the raw preform 232 and fibers are drawn therefrom.

While this invention has been described with reference to certain preferred embodiments, it will be appreciated that it could be varied in many ways. For example, one is not required to use the cladding process herein described to form the preforms. Other methods could be used, if desired. Similarly, the tapered fibers so formed could be used in embodiments other than the particular devices shown herein. Accordingly, the invention may be modified or applied in ways beyond those shown specifically in this application. The invention is as defined by the following claims.

What Is Claimed Is:

1.

A fused and drawn plastic fiber optic reducer comprised of a plurality of plastic optical fiber members arranged in an array with one end of said array having a cross-sectional area substantially larger than the other end of said array.

2.

The reducer of Claim 1 wherein said fiber members are first fused into a boule and then drawn to create the end with a reduced cross-sectional area.

3.

The reducer of Claim 2 wherein said plastic optical fiber members are arranged in a substantially orthogonal array within said boule.

4.

The reducer of Claim 3 wherein each of said reducer ends has a substantially flat face and the fiber members fill substantially all of each of said faces.

5.

The reducer of Claim 4 wherein each of said fiber members has a flat surface at each end thereof, the plurality of said flat surfaces forming said flat faces, and wherein each of said flat surfaces has substantially the shape of a polygon.

6.

The reducer of Claim 2 wherein each of said plastic optical fiber members is itself comprised of a fused and drawn plastic fiber optic bundle, said bundles being arranged in an array, the reducer being thereby comprised of an array of arrays.

7.

The reducer of Claim 6 wherein said plastic optical fibers are arranged in a substantially orthogonal array within each of said fiber bundles.

8.

The reducer of Claim 7 wherein each of said reducer ends has a substantially flat face and the bundle members fill substantially all of said face.

9.

The reducer of Claim 8 wherein each of said bundle members has a flat surface at each end thereof, the plurality of said flat surfaces forming said flat faces, and wherein each of said flat surfaces has substantially the shape of a polygon.

10.

The reducer of Claim 6 wherein each of said plastic fiber optic bundles is itself comprised of a plurality of plastic optical fibers arranged in an array, the reducer being thereby comprised of an array of arrays which are themselves arrays.

11.

The reducer of Claim 10 wherein said plastic optical fibers are arranged in a substantially orthogonal array within each fiber bundle.

12.

A plastic fiber optic reducer comprised of a plurality of plastic optical fiber members fused into an array, said array being drawn to thereby substantially reduce the cross-sectional area of one of the ends thereof.

13.

The reducer of Claim 12 wherein each of said plastic optical fiber members is itself comprised of a plurality of fused and drawn plastic fiber optic bundles arranged in an array, each of said bundles comprising a plurality of plastic optical fibers arranged in an array, each of said fiber member array, said bundle array and said fiber array being substantially orthogonal.

14.

The reducer of Claim 13 wherein each of said fibers is individually clad with a plastic material having a different index of refraction than the plastic material from which said fibers are made.

15.

The reducer of Claim 14 wherein each of said fibers is substantially square and each of said fiber member array and bundle array are square, and wherein one end of said reducer has approximately 1/16 the width and 1/16 the length of the other end of said reducer.

16.

An apparatus for generating a reduced-scale optical image of a beam pattern produced by directing a gamma-ray or x-ray irradiating beam through an object along a predetermined path, comprising:

an assembly of plastic optical fibers which have input end regions disposed in a two-dimensional input array which encompasses the area of the beam pattern, and output ends which are disposed in a reduced-scale two-dimensional output array, said input and output arrays being coherent, and

means for converting the irradiating beam pattern to a pattern of visible light whose density distribution is directly related to the impinging irradiating beam, said pattern being transmitted by said fibers to their output end to form a reduced-scale image of the beam pattern produced.

17.

The apparatus of Claim 16 wherein the fibers in said assembly have tapered cross-sectional areas on progressing from their input to output ends, and are arranged so that the fiber input ends form the input array, and the fiber output ends form the output array.

18.

The apparatus of Claim 17 wherein the fiber assembly is composed of an array of fiber reducers having input and output ends which make up the input and output arrays, respectively, where each reducer is formed of a fiber array of fused optical fibers, and where the fibers forming each reducer are drawn, in fused form, to produce the reduced cross-sectional area on progressing from the reducer's input to output end.

19.

The apparatus of Claim 18 wherein each of the fiber reducers comprising the array of fiber reducers has an approximately right angle bend between the input and output arrays.

20.

The apparatus of Claim 18 wherein the cross-sectional area of the arrays is reduced between about 25-200 fold between said input and output arrays.

21.

The apparatus of Claim 20 wherein each reducer includes between about 100-400 fibers.

22.

The apparatus of Claim 17 wherein the fiber assembly is composed of an image array of fiber reducers having input and output ends which make up the input and output arrays, respectively, where each reducer is formed of an array of fused optical fiber bundles, each bundle is formed of a fiber array of optical fibers, and the array of fiber bundles making up each reducer has been drawn, in fused form, to produce a reduced cross-sectional area on progressing from the reducer's input to output end.

23.

An apparatus for generating a reduced-scale high resolution optical image of an irradiating beam pattern produced by directing a gamma-ray or x-ray irradiating

beam through an object along a predetermined path, comprising:

means for converting the irradiating beam pattern which passes through the object to a visible light pattern whose density distribution is directly related to the passed irradiating beam pattern, thereby forming a non-reduced scale optical image,

a plastic fiber optic image reducer assembly having an input array which encompasses the area of the irradiating beam pattern and upon which the non-reduced scale optical image is directed and an output array from which the reduced scale optical image is outputted,

said assembly composed of a plurality of plastic fiber reducer subassemblies, each of said subassemblies being in turn composed of a plurality of fused plastic optical fibers, the plastic fibers in said subassemblies having input and output ends and having tapered cross-sectional areas progressing from their input to output ends,

the plastic fibers within each subassembly being ordered and aligned with one another so that the two-dimensional relationship of the ends of the plastic fibers in the input end of the subassembly is accurately duplicated in the output end of the subassembly, and

the reducer subassemblies being ordered and aligned with one another so that the two-dimensional relationship of the ends of the subassemblies in the input array is accurately duplicated in the output array, thereby providing a precise high resolution reduced scale optical image of the irradiating beam pattern.

24.

The apparatus of Claim 23 wherein said taper in said subassemblies has been produced by each subassembly of fused plastic fibers.

25.

The apparatus of Claim 23 wherein the image reducer assembly has an approximately right angle bend between the input and output arrays.

26.

The apparatus of Claim 23 wherein the cross-sectional area of the assembly is reduced between about 25-200 fold between input and output ends.

27.

The apparatus of Claim 26 wherein each subassembly includes between about 100-400 plastic fibers.

28.

An apparatus for generating a reduced-scale high resolution optical image of an irradiating beam pattern produced by directing a gamma-ray or x-ray irradiating beam through an object along a predetermined path, comprising:

means for converting the irradiating beam pattern which passes through the object to a visible light pattern whose density distribution is directly related to the passed irradiating beam pattern, thereby forming a non-reduced scale optical image,

a plastic fiber optic reducer assembly having an input array which encompasses the area of the irradiating beam pattern and upon which the non-reduced scale optical image is directed and an output array from which the reduced scale optical image is outputted,

said assembly being composed of a plurality of plastic fiber reducer subassemblies, each of said subassemblies being in turn composed of a plurality of fused plastic optical fiber bundles, the plastic fiber bundles in said subassemblies having input and output ends and having tapered cross-sectional areas progressing from their input to output ends,

the plastic fiber bundles within each subassembly being ordered and aligned with one another and the plastic fibers within each bundle being ordered and aligned

with one another so that the two-dimensional relationship of the ends of the plastic fibers and plastic fiber bundles in the input end of the subassembly is accurately duplicated in the output end of the subassembly, and

the reducer subassemblies being ordered and aligned with one another so that the two-dimensional relationship of the ends of the subassemblies in the input array is accurately duplicated in the output array, thereby providing a precise high resolution reduced scale optical image of the irradiating beam pattern.

29.

The apparatus of Claim 28 wherein the plurality of plastic fiber bundles making up each subassembly has been drawn in fused form to produce said tapered cross-sectional areas.

30.

An apparatus for generating a reduced-scale high resolution optical image of an irradiating beam pattern produced by directing a gamma-ray or x-ray irradiating beam through an object along a predetermined path, comprising:

means for converting the irradiating beam pattern which passes through the object to a visible light pattern whose density distribution is directly related to the passed irradiating beam pattern, thereby forming a non-reduced scale optical image,

a plastic fiber optic image reducer assembly having an input array which encompasses the area of the irradiating beam pattern and upon which the non-reduced scale optical image is directed and an output array from which the reduced scale optical image is outputted,

said assembly being composed of a plurality of fused plastic optical fibers, the plastic fibers having input and output ends and having tapered cross-sectional areas progressing from their input to output ends, said

tapers having been produced by drawing the assembly of fused plastic fibers, and

the plastic fibers being ordered and aligned with one another so that the two-dimensional relationship of the ends of the plastic fibers in the input end of the assembly is accurately duplicated in the output end of the assembly, thereby providing a precise high resolution reduced scale optical image of the irradiating beam pattern.

31.

The apparatus of Claim 30 wherein the image reducer assembly has an approximately right angle bend between the input and output arrays.

32.

The apparatus of Claim 30 wherein the cross-sectional area of the assembly is reduced between about 25-200 fold between input and output ends.

33.

The apparatus of Claim 32 wherein the assembly includes between about 100-400 plastic fibers.

34.

A method to verify the radiation dose pattern in radiation treatment which method comprises:

creating a real-time reduced optical image of the irradiation pattern produced by directing a gamma-ray or x-ray irradiating beam through the subject to be treated by causing said irradiation pattern to contact a means for converting said irradiating beam pattern to a visible light pattern whose density distribution is directly related to the passed irradiating beam pattern, thereby forming a non-reduced scale optical image; and

causing said optical image to contact a plastic fiber optic image reducer assembly having an input array which encompasses the area of the irradiating beam pattern and upon which the non-reduced scale optical image is directed and an output array from which the reduced

scale optical image is outputted, said assembly being composed of a plurality of plastic fiber reducer subassemblies each of said subassemblies being in turn composed of a plurality of fused plastic optical fibers, the plastic fibers in said subassemblies having input and output ends and having tapered cross-sectional areas progressing from their input to output ends, the plastic fibers within each subassembly being ordered and aligned with one another so that the two-dimensional relationship of the ends of the plastic fibers in the input end of the subassembly is accurately duplicated in the output end of the subassembly, and the reducer subassemblies being ordered and aligned with one another so that the two-dimensional relationship of the ends of the subassemblies in the input array is accurately duplicated in the output array, thereby providing a precise high resolution reduced scale optical image of the irradiating beam pattern.

35.

A method to verify the radiation dose pattern in radiation treatment which method comprises:

creating a real-time reduced optical image of the irradiation pattern produced by directing a gamma-ray or x-ray irradiating beam through the subject to be treated by causing said irradiation pattern to contact a means for converting said irradiating beam pattern to a visible light pattern whose density distribution is directly related to the passed irradiating beam pattern, thereby forming a non-reduced scale optical image; and

causing said optical image to contact a plastic fiber optic image reducer assembly having an input array which encompasses the area of the irradiating beam pattern and upon which the non-reduced scale optical image is directed and an output array from which the reduced scale optical image is outputted, said assembly composed of a plurality of plastic fiber reducer subassemblies

each of said subassemblies being in turn composed of a plurality of fused plastic optical fiber bundles, the plastic fiber bundles in said subassemblies having input and output ends and having tapered cross-sectional areas progressing from their input to output ends, the plastic fiber bundles within each subassembly being ordered and aligned with one another and the plastic fibers within each bundle being ordered and aligned with one another so that the two-dimensional relationship of the ends of the plastic fibers and plastic fiber bundles in the input end of the subassembly is accurately duplicated in the output end of the subassembly, and the reducer subassemblies being ordered and aligned with one another so that the two-dimensional relationship of the ends of the subassemblies in the input array is accurately duplicated in the output array, thereby providing a precise high resolution reduced scale optical image of the irradiating beam pattern.

36.

A method to verify the radiation dose pattern in radiation treatment which method comprises:

creating a real-time reduced optical image of the irradiation pattern produced by directing a gamma-ray or x-ray irradiating beam through the subject to be treated by causing said irradiation pattern to contact a means for converting said irradiating beam pattern to a visible light pattern whose density distribution is directly related to the passed irradiating beam pattern, thereby forming a non-reduced scale optical image; and

causing said optical image to contact a plastic fiber optic image reducer assembly having an input array which encompasses the area of the irradiating beam pattern and upon which the non-reduced scale optical image is directed and an output array from which the reduced scale optical image is outputted, said assembly composed of a plurality of fused plastic optical fibers, the plas-

tic fibers in said assemblies having input and output ends and having tapered cross-sectional areas progressing from their input to output ends, said tapers having been produced by drawing the assembly of fused plastic fibers, the plastic fibers within each assembly being ordered and aligned with one another so that the two-dimensional relationship of the ends of the plastic fibers in the input end of the assembly is accurately duplicated in the output end of the assembly, thereby providing precise high resolution reduced scale optical image of the irradiating beam pattern.

37.

An apparatus for generating a reduced-scale optical image of a beam pattern produced by directing a high energy irradiating beam through an object along a predetermined path, comprising:

an assembly of plastic optical fiber elements which have input end regions disposed in an input array which encompasses the area of the beam pattern, and output ends which are disposed in a reduced scale two-dimensional output array, said arrays being oriented in planes which are substantially non-parallel, said fiber elements being joined at their ends to form said arrays and being otherwise substantially separated along their lengths to accommodate the change in orientation between said input and output arrays, and

means for converting the irradiating beam pattern to a pattern of visible light whose density distribution is directly related to the impinging irradiating beam, said pattern being transmitted by said fibers to their output ends, to form a reduced-scale image of the beam pattern produced.

38.

The apparatus of Claim 37 wherein said input array is comprised of a plurality of said fiber elements positioned adjacent each other and along their length and

said output array is comprised of an orthogonal array of said fiber element ends.

39.

The apparatus of Claim 38 wherein said irradiating beam converting means further comprises a linear array interposed between said irradiating beam and said input array, and means for moving said linear array across said input array.

40.

The apparatus of Claim 39 wherein said linear array further comprises means for converting said irradiating beam into radiation of a first wavelength and wherein said fiber ends comprising said input array are doped so that as said first wavelength radiation impinges thereon, visible light is emitted in said fiber ends.

41.

The apparatus of Claim 39 wherein said irradiating beam converting means further comprises doping in said input array fiber ends.

42.

The apparatus of Claim 38 wherein said irradiating beam converting means further comprises doping in said input array fiber ends, and means for rotating said input array about an axis substantially parallel to said irradiating beam.

43.

An apparatus for generating a reduced-scale optical image of a beam pattern produced by directing a high energy irradiating beam through an object along a predetermined path, comprising:

an input array comprised of a plurality of plastic optical fibers laid substantially adjacent to each other along a length thereof, said length of adjacent fibers being sufficient, and the overall width of said plurality of fibers being sufficient, to encompass the area of the beam pattern,

a reduced scale output array comprised of the tips of said plurality of fibers packed into a substantially orthogonal array, and

means for converting the irradiating beam pattern to a pattern of visible light, said pattern being transmitted by said fibers to their output ends, to form a reduced-scale image of the beam pattern produced.

44.

The apparatus of Claim 43 wherein said irradiating beam converting means further comprises doping in said input array.

45.

The apparatus of Claim 44 wherein said irradiating beam converting means further comprises a linear array interposed between said irradiating beam and said input array, and means for moving said linear array across said input array.

46.

The apparatus of Claim 45 wherein said linear array further comprises means for converting said irradiating beam into radiation of a first wavelength and wherein said doping includes means for emitting visible light in response to the bombardment by radiation of said first wavelength.

47.

The apparatus of Claim 43 wherein said irradiating beam converting means further comprises means for rotating said input array about an axis substantially parallel to said irradiating beam.

48.

A method for forming a tapered plastic optical fiber reducer array comprised of a plurality of tapered individually cladded plastic optical fibers, said method comprising the steps of:

arranging a plurality of non-tapered, individually cladded, plastic optical fibers into an array;

fusing said array into a boule;

heating said boule above its melting point along a length thereof while said boule is held under tension to thereby draw a taper in said length thereof; and

trimming the ends from said length to thereby form the tapered reducer array.

49.

The method of Claim 48 wherein the step of heating the boule includes the step of advancing an oven at a controlled rate along said length of said boule.

50.

The method of Claim 49 wherein the step of fusing further comprises the steps of:

heating the array under vacuum to a temperature sufficient to fuse adjacent fibers;

permitting the array to cool to a temperature below said fusing temperature;

heating the array a second time to a temperature sufficient to fuse adjacent fibers; and

permitting the array to cool to a temperature below said fusing temperature.

51.

The method of Claim 50 further comprising the steps of wrapping said array and enclosing said wrapped array inside a tube which snugly surrounds said array prior to each heating.

52.

The method of Claim 51 wherein said arrays are wrapped with Teflon™ or the like for said first heating and said arrays are wrapped with both Teflon™ or the like and Mylar™ or the like for said second heating.

53.

The method of Claim 52 wherein said first heating step includes the step of heating the boule to about

125°C, and the second heating step includes the step of heating the boule to about 147°C.

54.

A method for forming a tapered reducer, said tapered reducer being comprised of a plurality of individually cladded plastic optical fibers, said tapered reducer array exhibiting a reduction in cross-sectional area between its input and output of about 1-256, said method comprising the steps of:

arranging a plurality of individually cladded plastic optical fibers into an array;

enclosing the array such that the individual fibers are constrained at least along their length;

heating said array in a first fusing to a temperature sufficient to fuse said adjacent fibers, said heating being done under vacuum;

permitting the array to cool to a temperature below said fusing temperature but elevated from room temperature;

heating said array in a second fusing to a temperature sufficient to fuse adjacent fibers, said second fusing being done at atmospheric pressure;

permitting the array to cool to a temperature below said fusing temperature; and

removing said boule from said enclosure and heating said boule along a length thereof while said boule is held under tension to thereby draw said length and form the tapered reducer array.

55.

The method of Claim 54 wherein the step of heating the boule includes the step of advancing an oven at a controlled rate along said length of said boule.

56.

The method of Claim 55 further comprising the step of wrapping said array in Teflon™ or the like prior to constraining said array, and wrapping said array with

both Teflon™ or the like and Mylar™ or the like prior to said second fusing, said array being constrained in said enclosure throughout both of said first and second fusings.

57.

A method for forming a boule comprised of a plurality of individually cladded plastic optical fibers, said boule being suitable for drawing under heat, said method comprising the steps of:

arranging a plurality of non-tapered, individually cladded, plastic optical fibers into an array;

heating the array under vacuum to a temperature sufficient to fuse adjacent fibers;

permitting the array to cool to a temperature below said fusing temperature;

heating the array a second time to a temperature sufficient to fuse adjacent fibers; and

permitting the array to cool to a temperature below said fusing temperature.

58.

The method of Claim 57 further comprising the steps of:

wrapping said array and enclosing said wrapped array inside a tube which snugly surrounds said array prior to each heating.

59.

The method of Claim 58 wherein said arrays are wrapped with Teflon™ or the like for said first heating and said arrays are wrapped with both Teflon™ or the like and Mylar™ or the like for said second heating.

60.

The method of Claim 59 wherein said first heating step includes the step of heating the boule to about 125°C, and the second heating step includes the step of heating the boule to about 147°C.

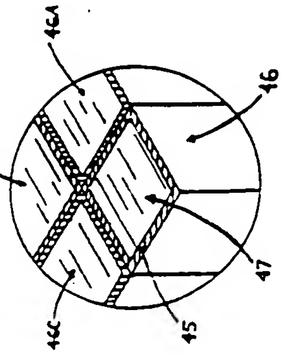


FIG. 3A

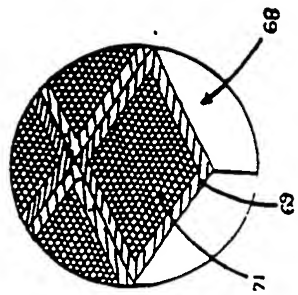


FIG. 4A

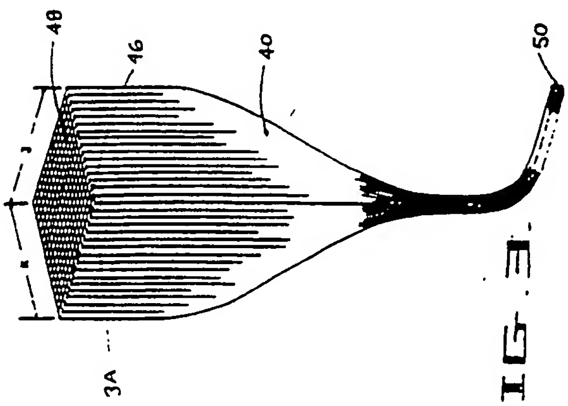


FIG. 3

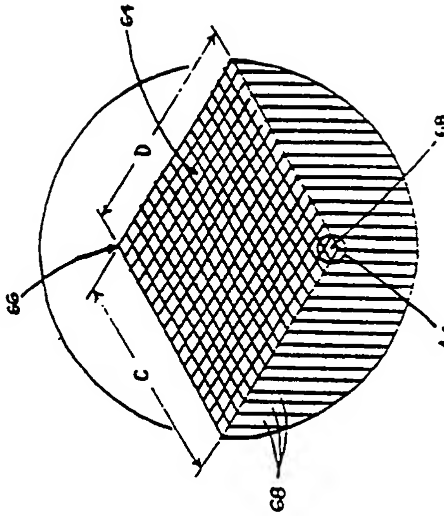


FIG. 4

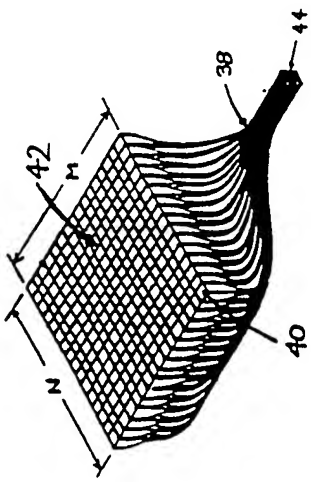


FIG. 2

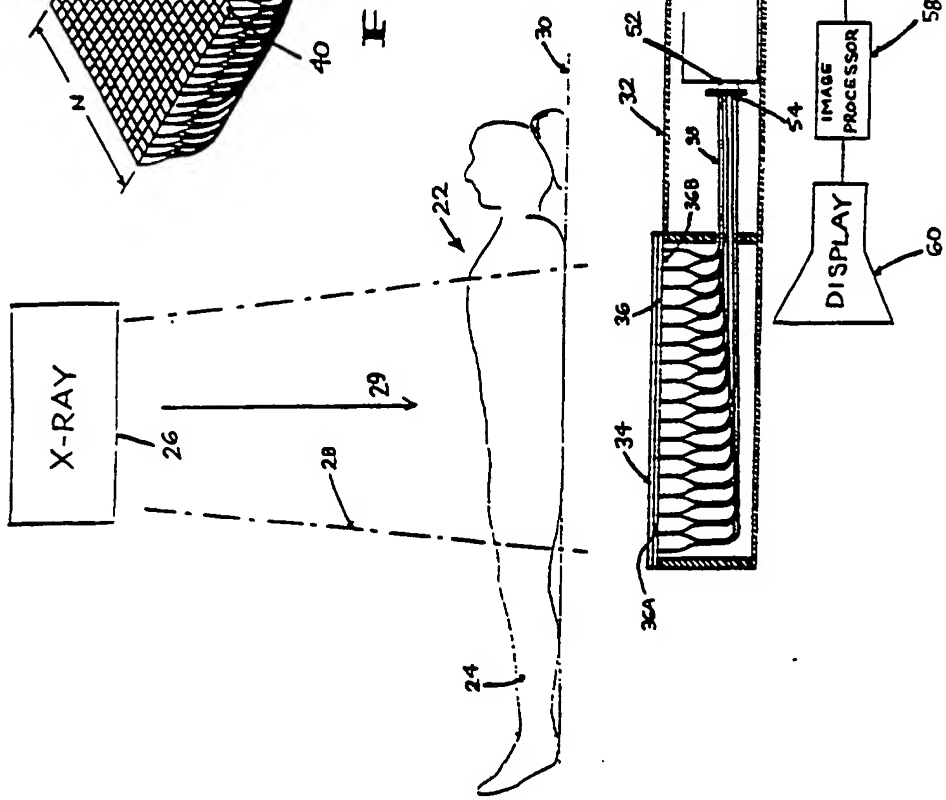


FIG. 1

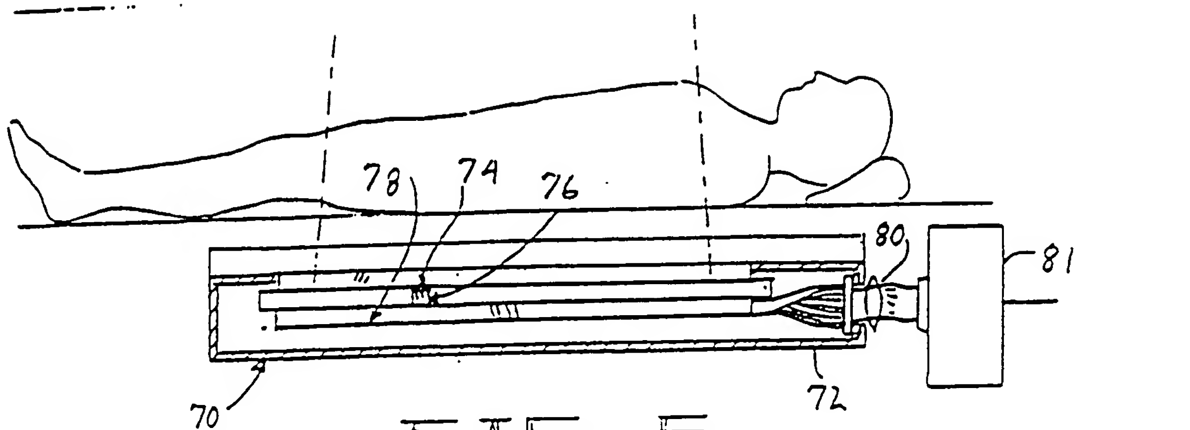


FIG. 5

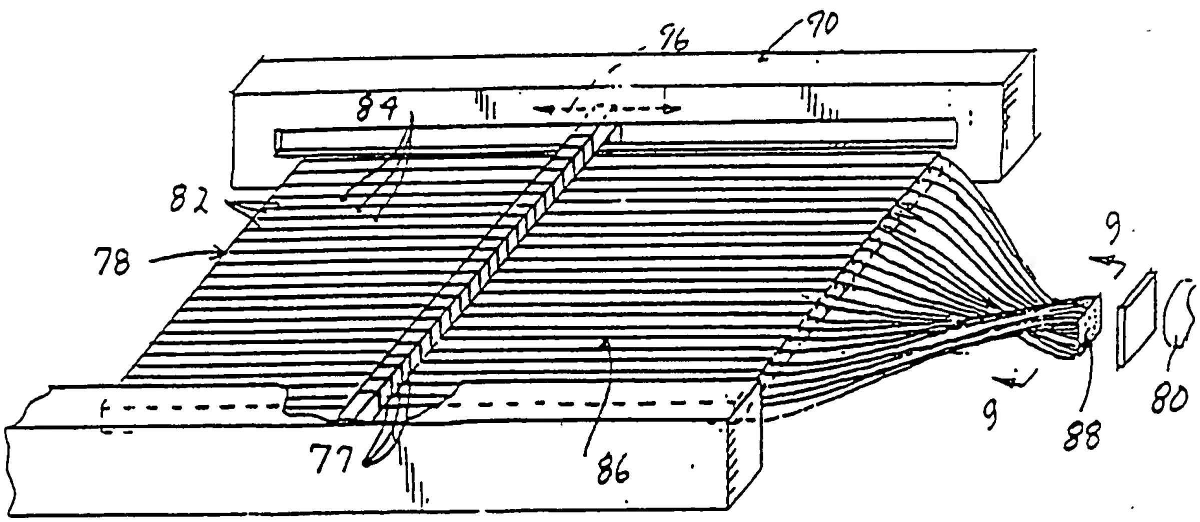


FIG. 6

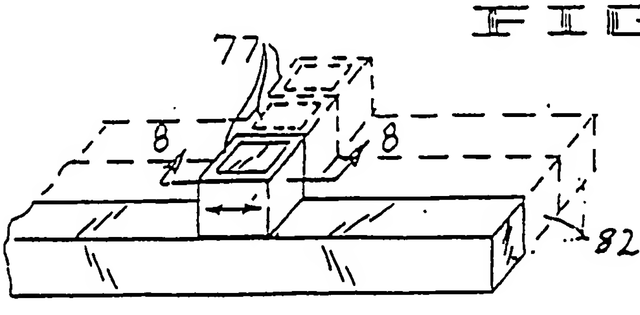


FIG. 7

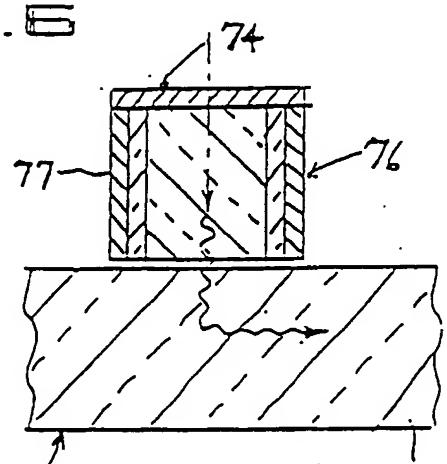


FIG. 8

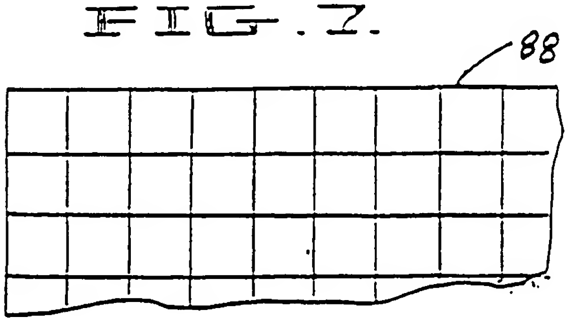


FIG. 9

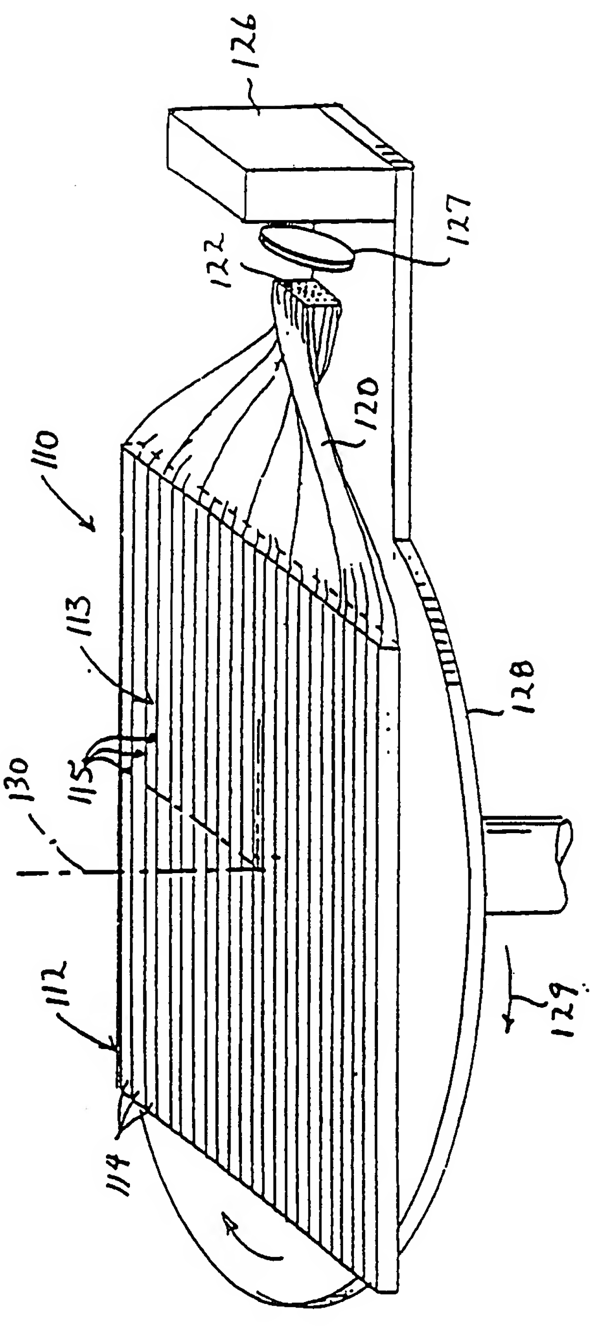


FIG. 10

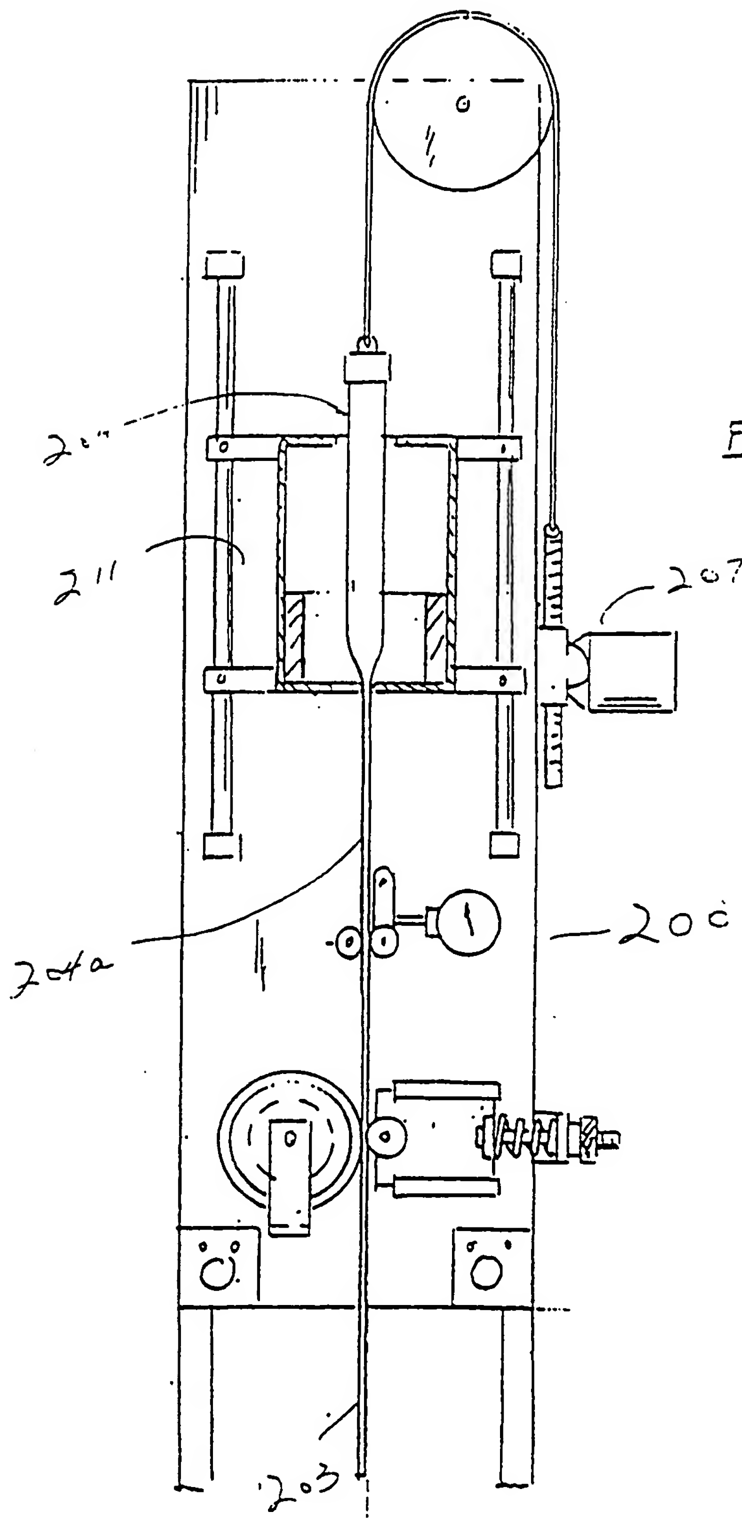


FIG.11

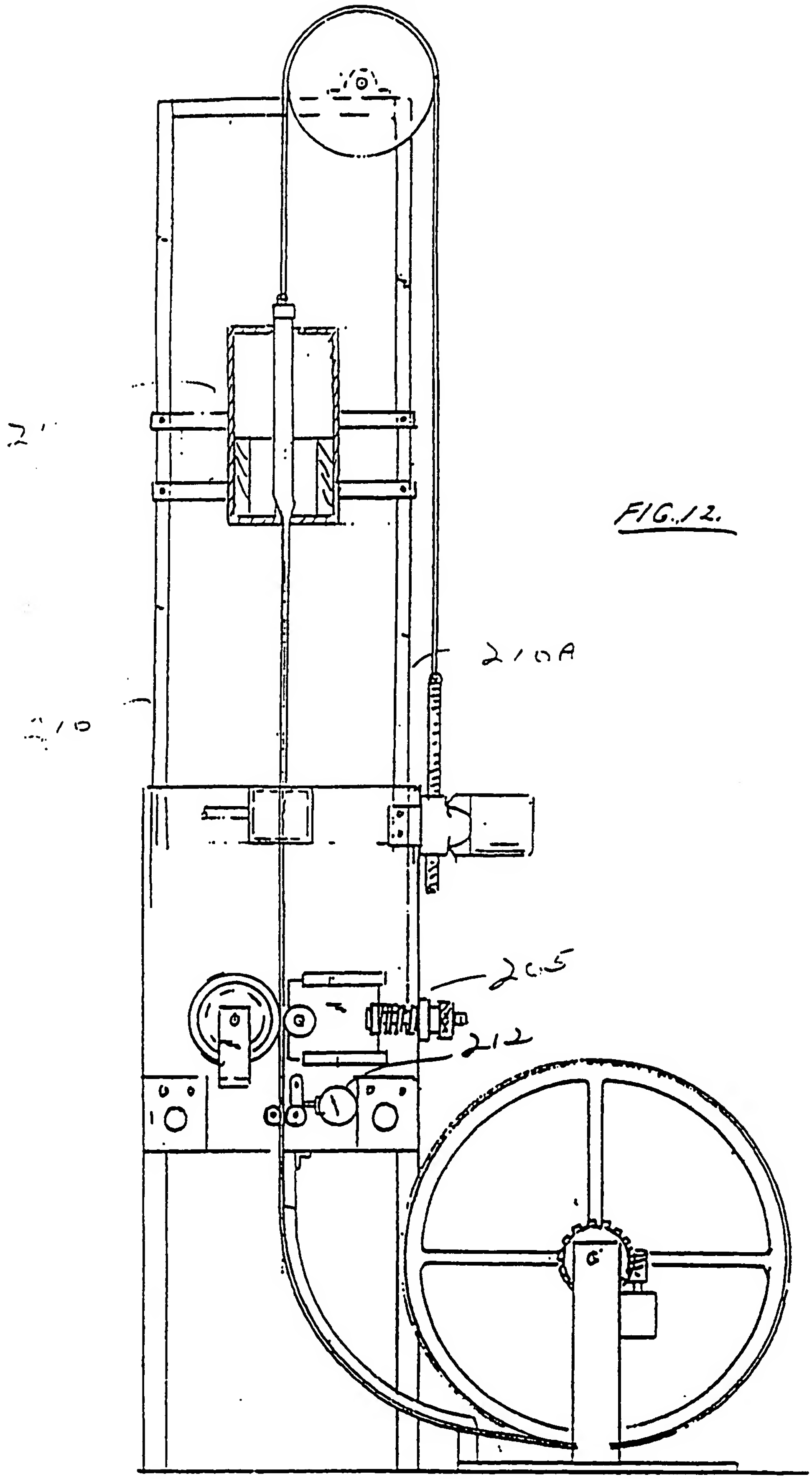


FIG. 12.

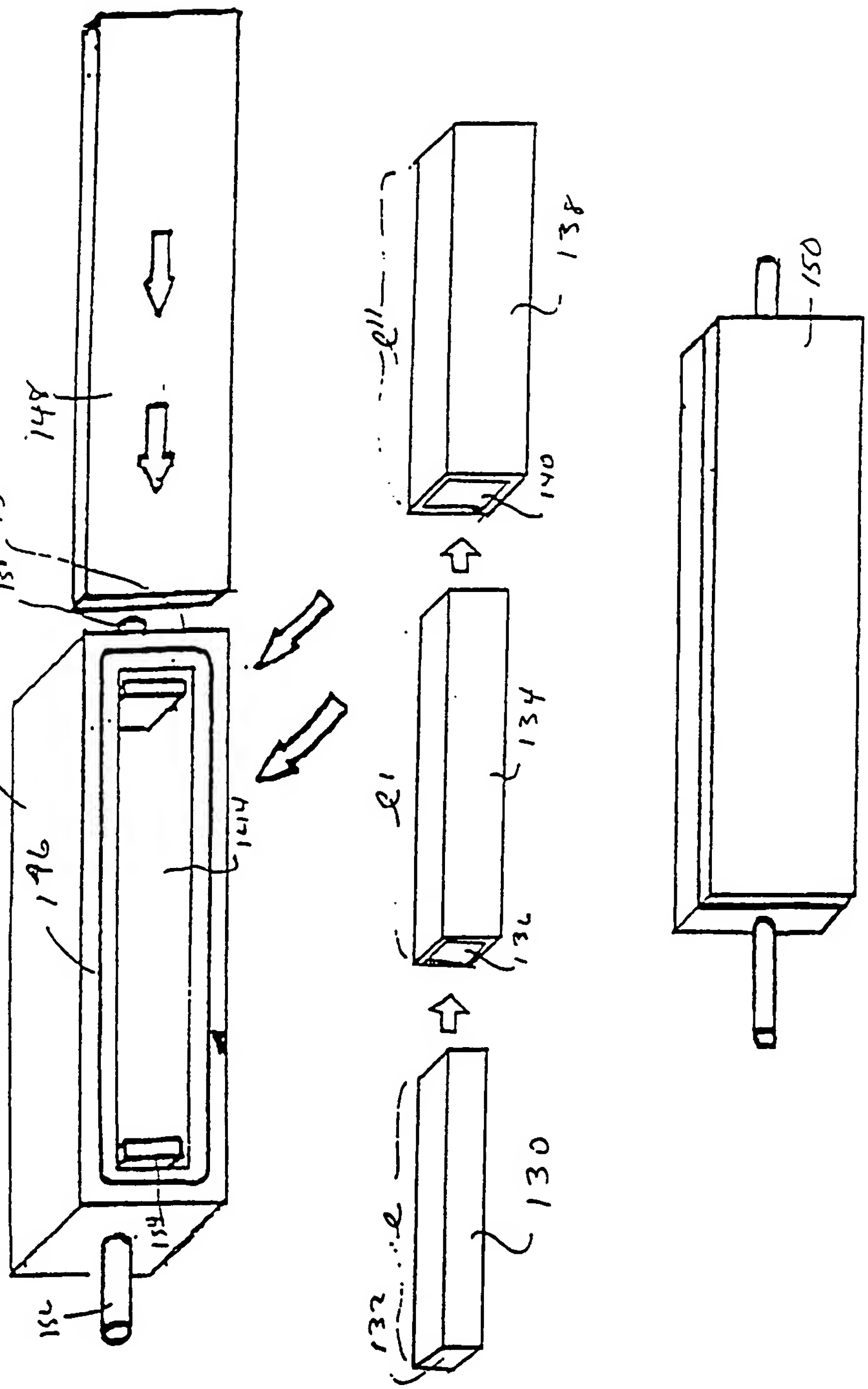


Fig. 13.

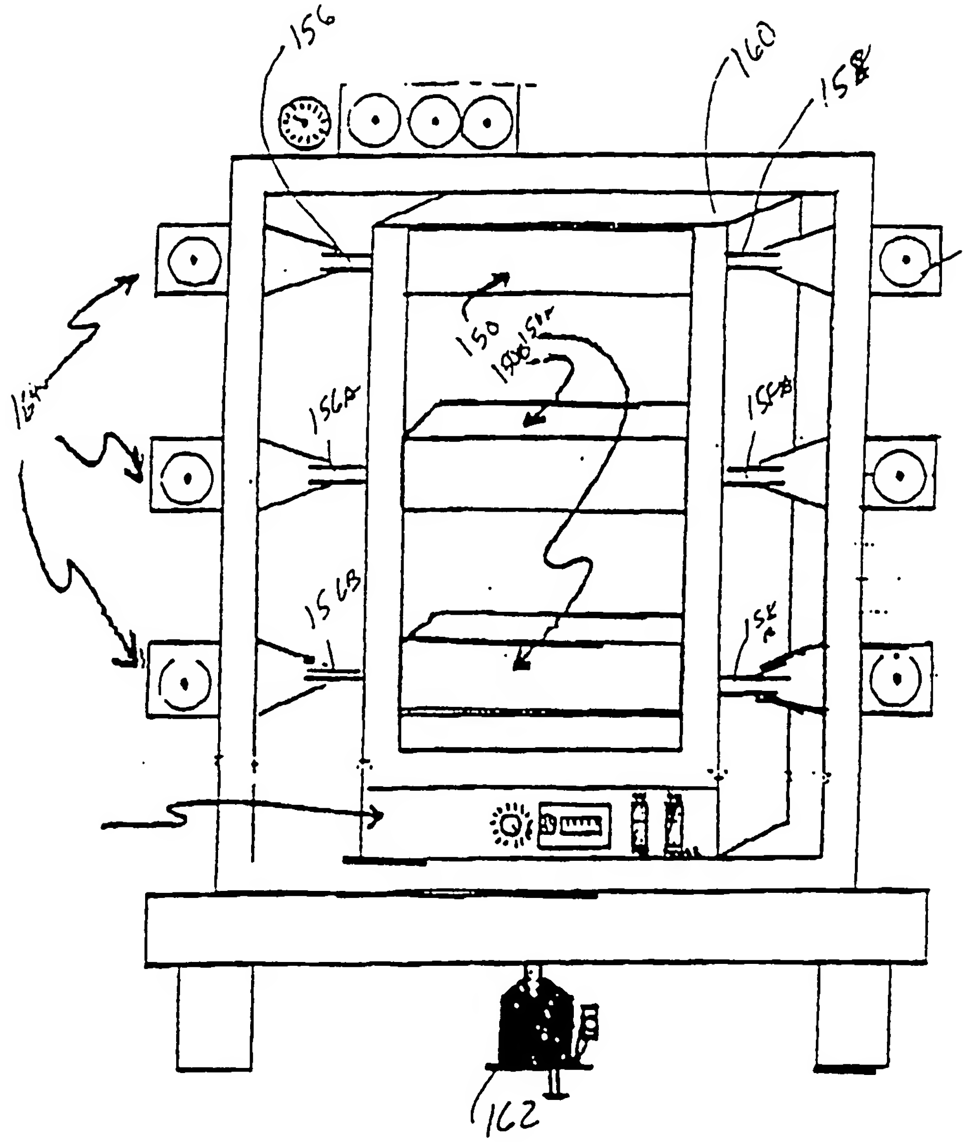


Fig 14

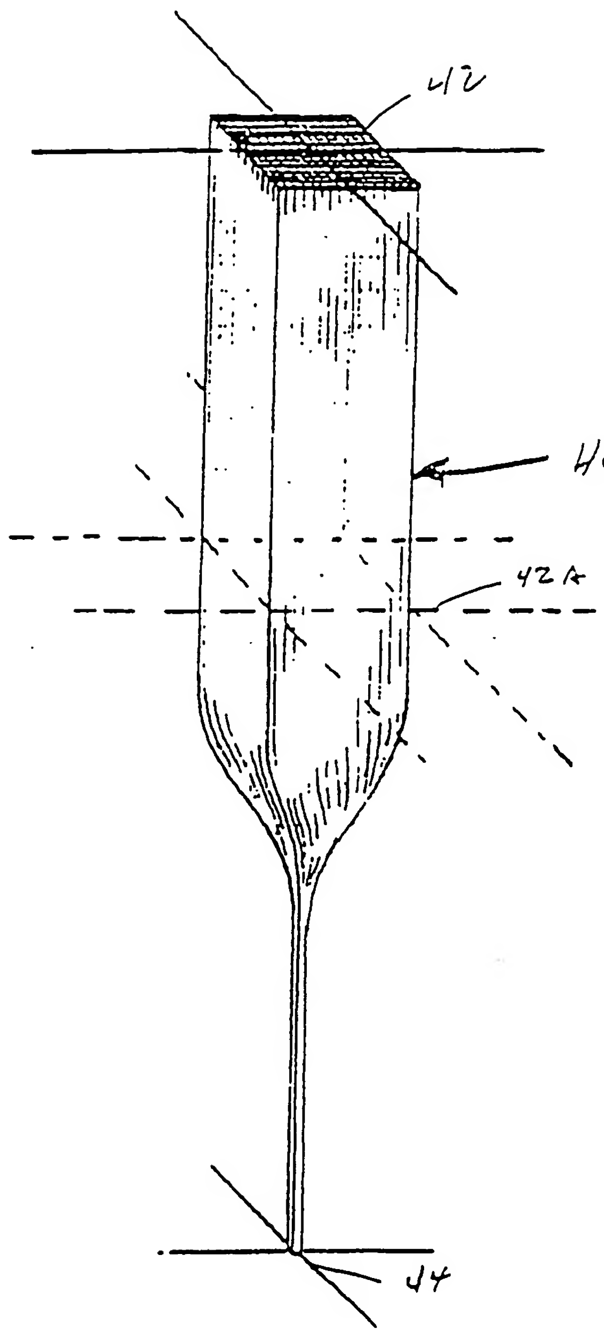


FIG. 15.

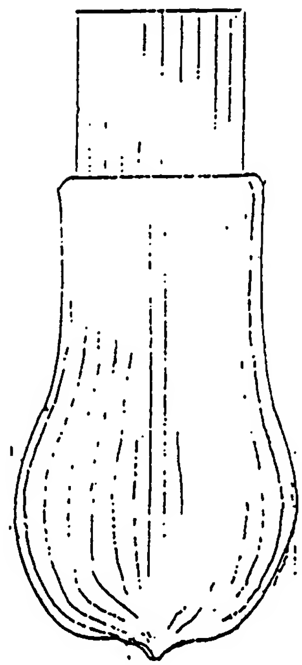


FIG. 16.

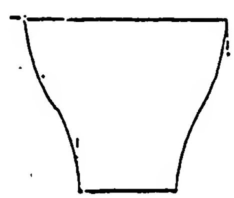
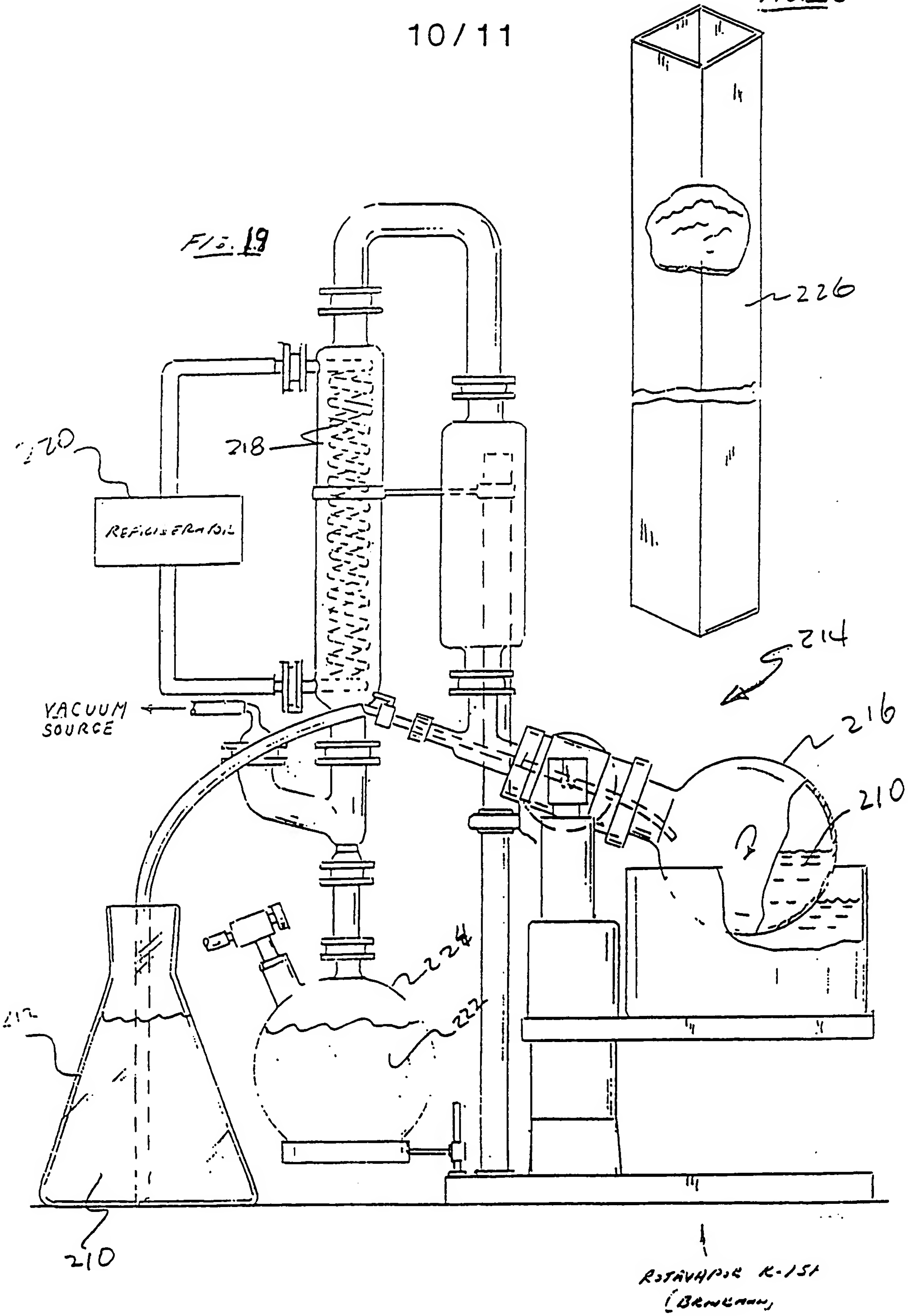


FIG. 17.

FIG. 20

FIG. 19


226
218
220
REFRIGERATION
VACUUM SOURCE
214
216
210
224
222
212
210
ROTAVAPOR R-151
(BRINKMANN)

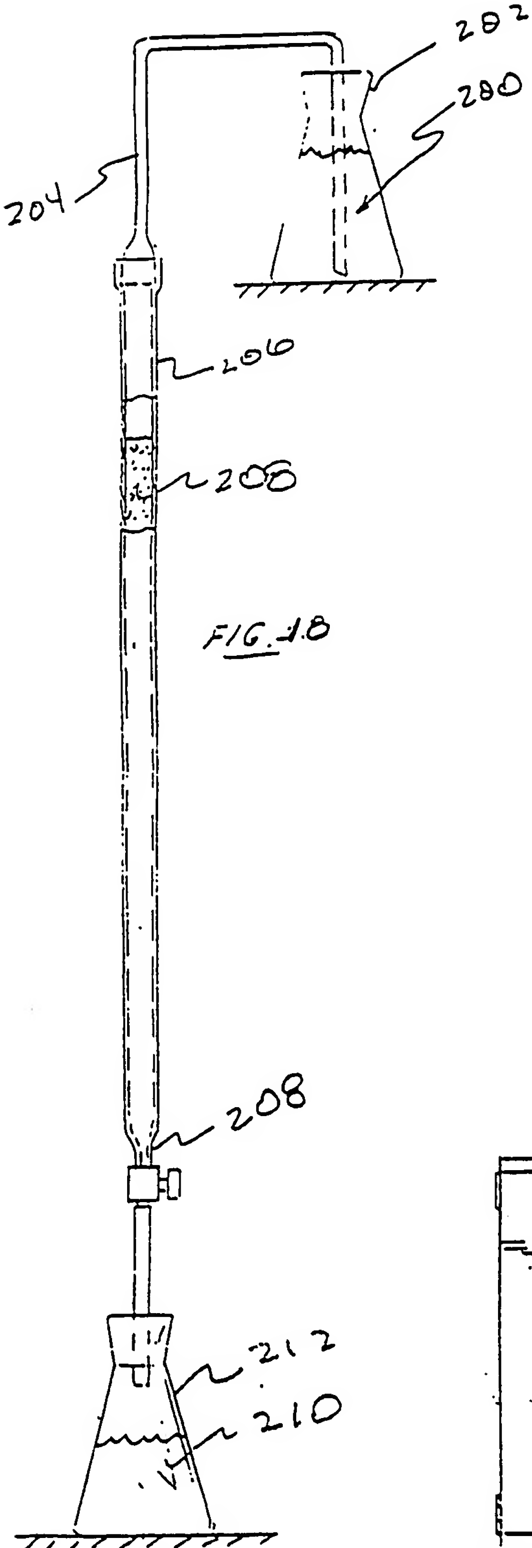


FIG. 18

FIG. 21

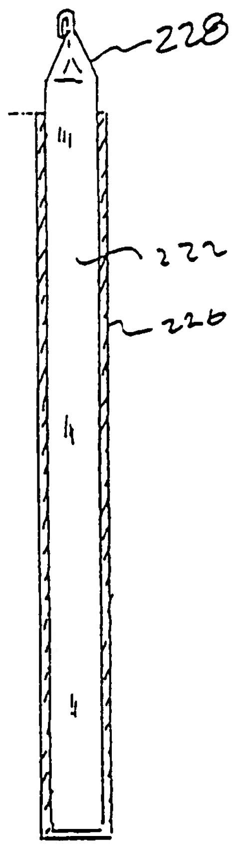
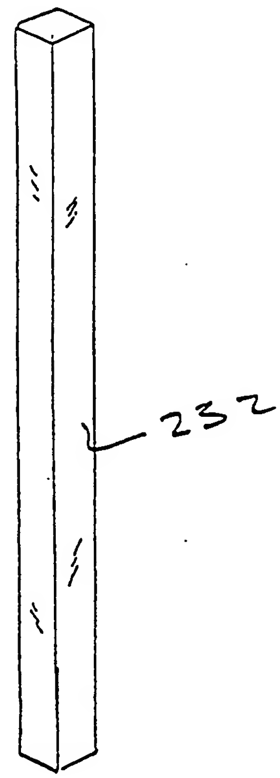


FIG. 23



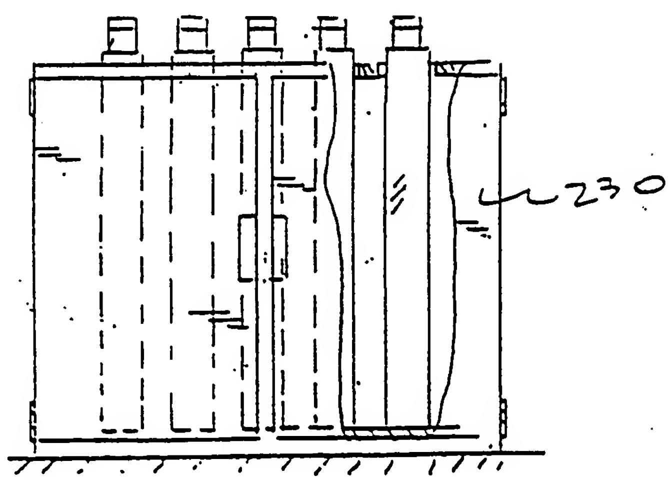


FIG. 22

INTERNATIONAL SEARCH REPORT

International Application No PCT/US91/02466

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): G02B 6/06
US CL.: 350/96.24

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
US	350/96.10, 96.24, 96.25, 96.26, 96.27 378/62, 63, 901

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 3,225,193 (HILTON ET AL.) 21 December 1965 See column 3, lines 5-38 and column 4, lines 14-36.	41,42,44-46
A	US, A, 3,238,837 (WOODCOCK) 08 March 1966 See column 2, lines 34-43 and column 3, lines 38-46.	1-33,37-47
A	US, A, 3,391,969 (OGLE) 09 July 1968 See figure 9, and column 1, lines 67 and column 2, line 7.	1-33,37-47
Y	US, A, 4,076,378 (COLE) 28 February 1978 See column 2, lines 26-31 and column 4, line 60 and column 5, line 6.	1-5,12,16,17, 30,32,33,37,38 43,48-60
X	US, A, 4,099,833 (TOSSWILL) 11 July 1978 See column 2, line 53 and column 3, line 47.	1-4,12,48,49
A	US, A, 4,768,857 (SAKUNAGA ET AL.) 06 September 1988, see entire document.	1-33,37-47
Y	US, A, 4,812,012 (TERADA ET AL.) 14 March 1989 See entire document.	1-33,37-47

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
02 JULY 1991	18 JUL 1991
International Searching Authority	**Signature of Authorized Officer**
ISA/US	NGUYEN NGOC-HO INTERNATIONAL DIVISION JOHN D. LEE

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

Y	US, A, 4,833,698 (FLANNERY ET AL.) 23 May 1989 See column 17, line 61 and column 18, line 9.	16-47

V ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

3. ☐ Claim numbers____________, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.